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13. ABSTRACT (Maximum 200 words) The Lane Mountain milkvetch (<i>Astragalus jaegerianus</i> Munz) is an endangered perennial herb and is one of few plant species narrowly endemic to the central Mojave Desert. Its populations are threatened primarily by physical disturbance and habitat fragmentation. Rare recruitment events and the plant's short life span result in extreme fluctuations in population size from high numbers following a successful recruitment year to very low numbers following several years of average or below average precipitation. Our field studies indicate that in addition to total precipitation, frequency and timing of precipitation are critical for successful recruitment. In a greenhouse study, we grew milkvetch under nine artificial rainfall treatments: 3 amounts (100, 150, and 200mm/wet season) x3 frequencies (1, 2, and 4 times per month) of precipitation. Our results indicate that 200 mm of precipitation with a frequency of four times per month is required for seedlings to attain a level of development that enables them to endure a summer drought and resprout in the next growing season. We conclude that exceptionally above average and frequent precipitation is required for recruitment to occur. Such conditions are estimated to occur once in about every 10 years in the central Mojave Desert.			
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Final Report

The Effect of Amount and Frequency of Precipitation on Seedling Establishment and Survival of Lane Mountain Milkvetch (*Astragalus jaegerianus* Munz)

Proposal number: 48641-EV

Report Prepared for:

Russell S. Harmon, Ph.D.
Senior Program Manager for Terrestrial Sciences
Environmental Sciences Division
Army Research Office (AMSRD-ARL-RO-EV)
US Army Research Laboratory
PO Box 12211
Research Triangle Park, NC 27709-2211
Tel: 919-549-4326
Fax: 919-549-4310
E-mail: russell.harmon@us.army.mil

Prepared by:

P. W. Rundel, B. Prigge, and M. R. Sharifi
Dept. of Ecology and Evolutionary Biology
University California, Los Angeles

Email: sharifi@biology.ucla.edu
Phone: (310) 825-8777
Fax: (310) 825-9433

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EXECUTIVE SUMMARY

Introduction: The Lane Mountain milkvetch (*Astragalus jaegerianus* Munz), here after LMMV, is an endangered, perennial herb and is one of only a few plant species narrowly endemic to the central Mojave Desert. Its populations are threatened primarily by physical disturbance and habitat fragmentation. Rare recruitment events and the plant's short life span result in extreme fluctuations in population size from relatively high numbers following a successful recruitment year to very low numbers following several years of average or below average precipitation. Our field studies indicate that in addition to total seasonal precipitation, frequency and timing of precipitation are critical for successful recruitment.

Our objectives in this study were:

- To determine the threshold for the amount and the frequency of precipitation for seedling growth and survival during the period between germination and summer dormancy.
- To determine effect of the amount and the frequency of precipitation on seedling development and maturation that enables them to survive a hot, dry summer and resprout with autumn or winter rains to become reproductive, mature plants in the next season and complete their life cycle.

These findings will be crucial for the restoration of impacted sites and the establishment of milkvetch on new sites.

GREENHOUSE STUDIES

Methods

Before the experiment could begin, a batch of seeds had to be germinated and the young seeds planted out. This was done to guarantee that the experimental part of the study would not be plagued by failure of seeds to germinate or early seedling death.

Seed Germination: All the seeds that we used for germination in this experiment were collected from greenhouse grown LMMV plants (12-15 months old) and were physically scarified. To minimize the effect of seed size on the treatments, we selected only large

(larger than 5.0mg) seeds for the experiment. After 71 hr in the growth chamber, 94% of all the seeds germinated with emergent cotyledons. After the first leaf (with 3 leaflets) emerged, the seedlings were transplanted into one of 15 plastic containers (35x35x10 cm), which were filled with a mixture of desert soil and Vermiculite. After transplanting, the plastic containers were placed in the growth chamber for 4-6 days.

When the seedlings had recovered from transplanting (indicated by new growth) in the growth chamber, the plastic containers were then moved to the greenhouse at UCLA, which was set to a day/night temperature of 23/18°C. Each seedling, when it was about 5-9 cm in height, was transplanted to a 4 inch diameter × 36 inch long PVC pipe, and was now set for testing the effect of frequency and amount of precipitation on seedling survival. The experiment was divided into three phases: watering, drought, and watering.

In the first watering phase, we grew the seedlings for 6 months under nine watering treatments: 3 total amounts (102, 153, and 203mm/wet season) × 3 watering frequencies (1, 2, and 4 times per month). Five days after transplanting the seedlings to PVC pots, we began our qualitative and quantitative phenological observations on all milkvetch seedlings. Our phenological observations included the measurement of the leading shoot length; total shoots length (lateral shoots), leaf growth, and flower and pod production. In June the day/night temperature of the greenhouse was increased to 33/22°C.

After completion of the watering phase, the plants were not watered for 3 months to mimic a typical summer drought of the central Mojave Desert. The plants either became dormant or died.

After the drought, the plants were watered with equivalent of 25 mm (1 inch) precipitation. To determine survivorship, the plants were checked for resprouts during the next weeks.

Results

- Our greenhouse results indicate that 203 mm (8 inches) rainfall with a frequency of four times per month is optimal for seedling establishment and survival of LMMV. Similar values are expected in its natural habitats.

- LMMV has a critical lower limit with respect to the amount and frequency of precipitation required for seedling survival, which is greater than the normal rain-year precipitation.
- The highest mortality occurred (100%) with the 200 mm (4 inches) of precipitation treatment for all three precipitations frequencies (4 times per week, 2 times per week and one time per week). The 8 inches precipitation treatment at the highest frequency (4 times rain events per week) had the lowest mortality.
- Seedling survival is greater under more frequent than less frequent precipitation.
- One week after resumption of watering after three months (July – October of 2006) summer drought the 33% of the plants from the 8 inches rain with 4 times watering frequencies per month and 7% of the 8 inches rain with 2 times watering frequencies per month resprouted.
- All the resprouted individuals exhibited healthy and vigorous growth, however only four individuals produced flowers and only one plant produced pods and seeds.
- Seedling survival and growth to maturity are crucial for maintaining sustainable populations of the Lane Mountains Milkvetch (LMMV).

FIELD STUDIES

We have monitored the following parameters in our permanent plots since 1999:

- The number of LMMV plants (categorized as alive or active, senesced, not present).
- Height of the actively growing plants
- Reproductive activity
- Number of seedlings
- Seedling height and number of leaves
- Herbivore damage of active LMMV plants

Results

- A wet year (such as 2004-2005) is crucial for LMMV seedlings establishment, but it may also promote the germination and growth of native and alien annuals that compete with and promote the herbivory of seedlings of LMMV.
- The increased precipitation and perhaps timing of precipitation stimulated unusually vigorous weed growth under and around the milkvetch nurse plant canopy, and thus inhibited milkvetch seedling growth and perhaps seed germination.
- Even after the unusually wet season of 2004-2005, we observed only 49 seedlings, of which only 8 survived into the spring of 2006 and became established seedlings.
- Summer rain may be critical for seedlings establishment and survival to the next wet season.

INTRODUCTION

The rare and endangered Lane Mountain milkvetch (*Astragalus jaegerianus* Munz) occurs in fragmented populations that are clustered into four fairly proximate areas of the central Mojave Desert (Figure 1; Charis 2002). Because of its limited distribution and the potential threat from military training, the U.S. Fish and Wildlife Service (1998) listed it as a federally endangered species in 1998. Although the reasons for its limited distribution are unknown and open to speculation, narrow physiological tolerances to environmental variables are sometimes hypothesized to explain similarly restricted ranges of other endemic species (Cain 1983). With edaphically restricted plants they are generally poor competitors off the substrate that they are adapted to and only compete well on their substrate as observed for serpentine tolerant species by Kruckeberg (1954, also see Brady et al. 2005). Several species of *Astragalus* are known to be selenium accumulators and are restricted to selenium substrates, but we did not find any selenium in soil samples (unpublished data) that could explain the limited distribution of the Lane Mountain milkvetch.

Lane Mountain milkvetch (LMMV) occurs in very specific habitats in the transition zone between creosote bush scrub and Joshua tree woodland (Prigge and Sharifi 2000) sometimes referred to as mixed desert scrub (Charis 2002). Over 5700 individual plants have been located in recent surveys and given UTM coordinates using Global Positioning System (GPS) units (Prigge and Sharifi 2000, Charis 2002).

Approximately two-thirds of the plants will occur within Fort Irwin boundaries after the proposed southern land expansion of the National Training Center [NTC}, Fort Irwin. Only one-third of the present population will exist outside the expanded fort boundaries. Currently there is no military training on any of the known milkvetch sites, but when training begins in the expansion area, some of the milkvetch populations will be impacted, and the continued survival of this species may require human intervention. Depending on the level of impact, the intervention may be as simple as protecting habitat

and monitoring populations, but if the impact is similar to the impact in other training areas of the NTC, more active

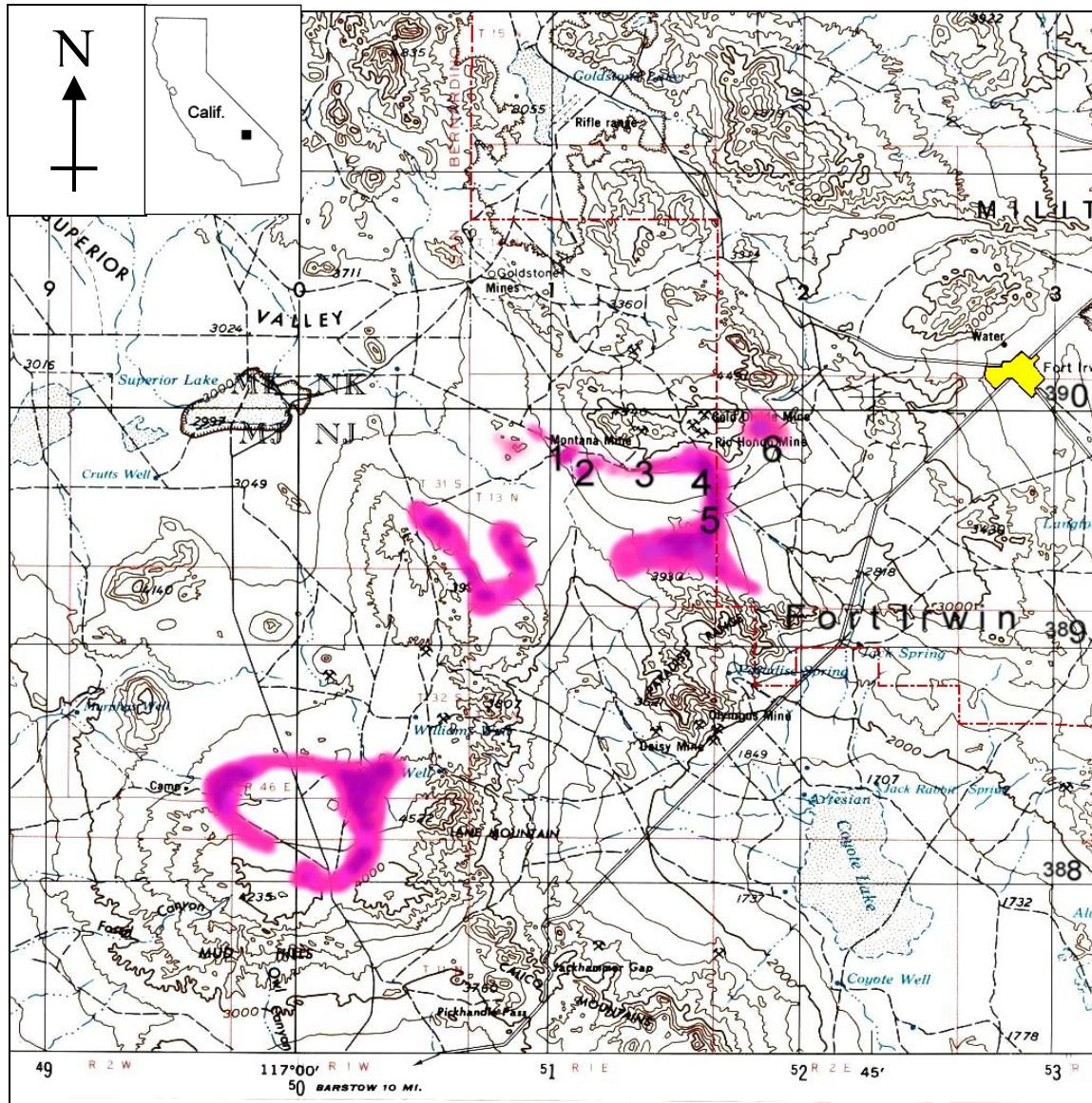


Figure 1. Distribution of Lane Mountain milkvetch (■) and the location of survey sites (numbered 1–6) in the central Mojave Desert, California.

intervention will be required. Such intervention might involve re-establishing populations by reseeding or planting nursery grown plants on former habitats or appropriate habitats not previously known to have this species, and possibly limiting training in certain areas during very wet winter and spring seasons when establishment and reproduction of the milkvetch is likely to occur.

The milkvetch faces a risk of extinction largely because of the following factors:

- Limited distribution (Prigge, Sharifi and Morafka 2000; Charis 2002),
- Large fluctuations in population size (Rundel, Prigge and Sharifi 2005),
- Threat of increased anthropogenic disturbance, resulting in death of individuals, and increased habitat fragmentation from off-road recreation (primarily dirt motorcycles) and military activity when Fort Irwin is expanded.
 - Potential decrease in population area resulting from the expansion of Fort Irwin.

Several aspects of the ecology and physiology of the Lane Mountain milkvetch have been studied to gain a better understanding of this species and the factors that may be limiting its distribution. Some of these are fairly well understood and others need further study.

These include:

- surveys and analyses of substrate, plant community, and nurse plants (Prigge, Sharifi and Morafka 2000) that have resulted in a fairly good understanding of the habitat characteristics, associated species, and nurse plant relationships of the milkvetch.
- A hypothesis of population dynamics (Rundel et al. 2005, Rutherford's ongoing studies since 1998) that permits one to make some approximate predictions of the future population size.
- Seed germination under controlled greenhouse and growth chamber conditions (Rundel et al. 2005) have shown that scarification of seeds resulted in 100% germination and that seeds germinate at almost any temperature but less so at higher temperature.

- Physiological studies by Gibson et al. (1988) have demonstrated that milkvetch plants:
 - Require high light (1400–1500 $\mu\text{mol m}^{-2} \text{s}^{-1}$) to achieve maximum photosynthetic rates, and, therefore, do not use the nurse plant for shade but as a trellis to climb on and elevate its leaves into direct sunlight, and
 - Are putative nitrogen fixers based on a study of stable isotope ratios of nitrogen in milkvetch (3.1% tissue nitrogen content) versus nurse plants and other associated species (1.8%).
- Insect pollination studies by Kearns (2003) and Hopkins (2005) have identified pollinators of the milkvetch, and we (the UCLA group) have conducted studies on cross- and self-pollination in the greenhouse (Sharifi et al 2005) demonstrating that pod production is higher for self-pollinated flowers (37%) than for cross-pollinated flowers (30%).
- Longevity studies on long-term monitoring plots at the Montana Mine site are being conducted by Rutherford (unpublished).
- The effect of dust on the milkvetch growth by Wijayratne et al. (2004)
- Population genetic variation by George Walker and Anthony Metcalf (California State University, San Bernardino).

Our understanding of other crucial aspects of the life history of this species, such as how environmental conditions affect seedling growth and survival to maturity is lacking. Soil water availability is one of the major limiting factors for seedling growth and survival in all desert ecosystems. For a rare desert perennial species with restricted habitats, such as the Lane Mountain milkvetch (*Astragalus jaegerianus* Munz), seed germination and seedling survival are vulnerable links in its life cycle. Weak links exacerbated by the high variability and low predictability in amount and timing of yearly precipitation in desert ecosystems. This low predictability raises questions concerning the germination characteristics of the seeds and seedling survivors, since the amount, timing and frequency of precipitation required for germination can be different from that required for

seedling survival. As a result, successful germination is sometimes followed by mortality of all seedlings.

Our surveys on survivorship and recruitment, have resulted in a rudimentary demographic model of the long-term population dynamics of the Lane Mountain milkvetch, one outcome is illustrated in Figure 2. This model lacks important long-term data on seedling recruitment, and the curves are not sensitive short-term variations in the timing and amount of precipitation, but do reflect the long-term, average effect of precipitation. Using this preliminary model of population size (Figure 2), which is based on observed population size (Prigge and Sharifi 2000, Rundel et al 2005), observed death rates, and historical weather data (Figure 3), it appears that rain-year precipitation may needs to be greater than 7 or 8 inches (18–20 cm) to have seedling establishment. However, frequency and timing of precipitation undoubtedly influences the effectiveness of precipitation with respect to seedling establishment, growth and survival. We believe the model is plausible, it will require modifications that incorporate the effect of long-term precipitation (timing and amount) on the amount of recruitment and on plant survivorship.

It is the insight gained from this model that has helped formulate our hypothesis that seedling recruitment only occurs in wet years ($> 18\text{cm}$ of precipitation) and that frequency of precipitation may also have an effect on seedling survival.

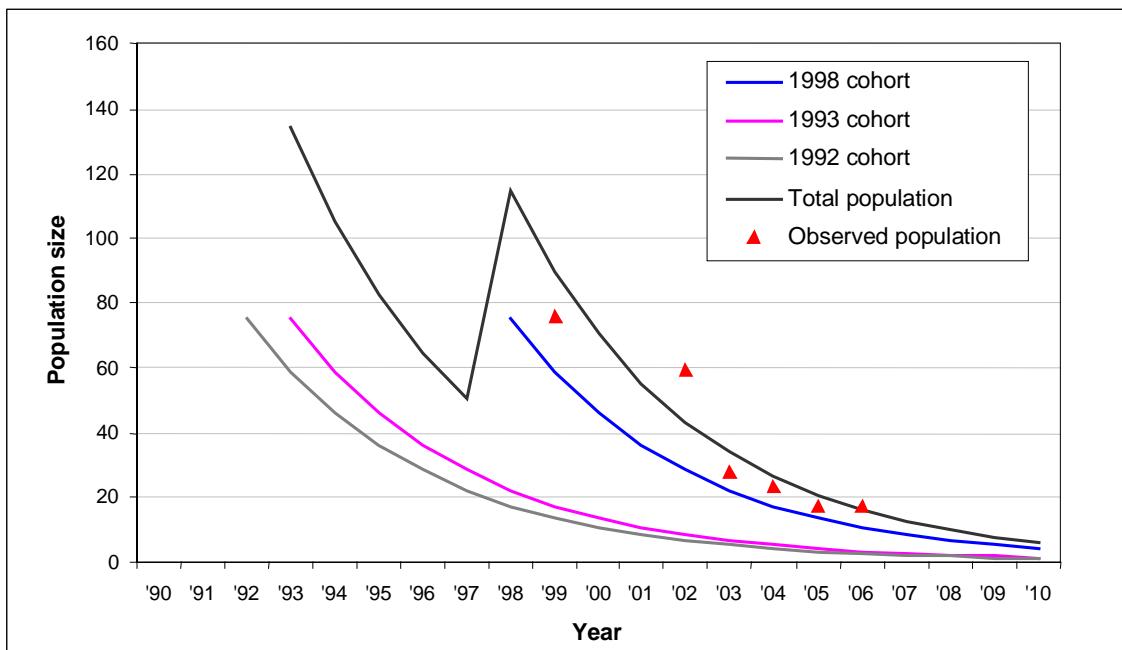


Figure 2. Hypothetical long-term population dynamics of the Lane Mountain milkvetch for the Montana Mine site, based on surveys from 1999 to 2006. Assumes three establishment years: 1992, 1993, and 1998.

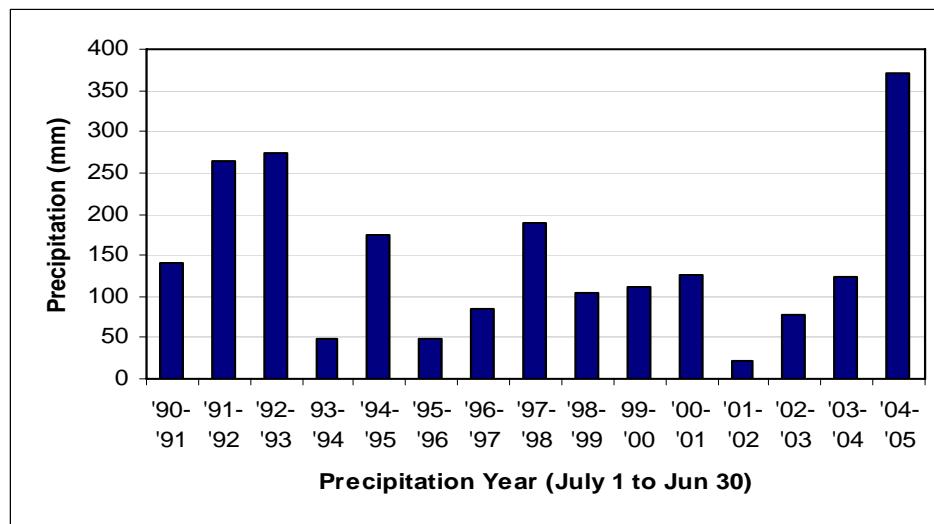


Figure 3. Annual precipitation for the milkvetch sites based on Goldstone Echo #2 weather station from 1990 to 1995 and an average of Goldstone Echo #2, TA Bravo, and Goldstone weather stations from 1995 to 2005. The data for 2005 is incomplete.

Objectives. Our main objectives are:

- a) To determine what is the most effective precipitation regime for seedling growth and survival of *Astragalus jaegerianus*? We accomplished this under controlled greenhouse condition by varying the frequency of precipitation from low to high and the amount of precipitation from moderate to high for a total of nine precipitation regimes.
- b) Conducted a parallel field study to monitor seedling growth and survival under natural habitats. The above average precipitation conditions of 2004-2005 provided us a unique opportunity to conduct field studies with milkvetch, which appears to have little or no seed germination and seedling establishment in any but unusually wet years.
- c) To determine the degree of development that Lane Mountain milkvetch seedlings must achieve to survive the summer drought and to resprout the next wet season?

Significance and Army relevance

Lane Mountain milkvetch, a narrowly endemic species, has a limited habitat range in the western Mojave Desert. A large portion of its habitat is located within the proposed expansion area for the National Training Center (NTC). Understanding the seedlings ecology (establishment, survival) and physiology (effect of water stress) of the milkvetch is vital to milkvetch conservation efforts towards re-establishment and persistence of this species. With the planned expansion of the National Training Center at Fort Irwin, the Lane Mountain milkvetch will face increased threats from disturbance and habitat fragmentation. Approximately two-thirds of the plants will occur within fort boundaries after the proposed southern land expansion of the NTC, Fort Irwin. Only one-third of the present population will exist outside the expanded fort boundaries. Currently there is no military training on any of the known milkvetch sites, but when training begins in the expansion area, some of the milkvetch populations will be impacted and the continued survival of this species may require human intervention. Depending on the level of impact, the intervention may be as simple as protecting habitat and monitoring populations, but if the impact is similar to the impact in other training areas of the NTC, more active intervention will be required. Such intervention might involve re-

establishing populations by reseeding or planting nursery grown plants on former habitats or appropriate habitats not previously known to have this species, and possibly limiting training in certain areas during very wet winter and spring seasons when establishment and reproduction of the milkvetch is likely to occur.

These threats will likely result in increased mortality and loss of populations. If left unchecked, increased habitat fragmentation could lead to the extinction of the species.

The results from studies like this are crucial for the development of plans for species management, revegetation, restoration, and introduction to new sites.

METHODS

Before the experiment could begin, a batch of seeds had to be germinated and the young seeds planted out. This was done to guarantee that the experimental part of the study would not be plagued by failure of seeds to germinate or early seedling death.

Seed Germination

All the seeds that we used for germination in this experiment were collected from greenhouse grown LMMV plants (12-15 months old. To minimize the effect of seed size on the treatments, we selected 270 seeds from the largest of three size classes [large (larger than 5.0mg), medium (3.5 – 5.0mg) and small (smaller than 3.5mg)] for the experiment. The seeds were physically scarified by placing them one by one on top of fine grit sandpaper and simultaneously rubbing them with another piece of sandpaper of the same type. Seeds were monitored under a dissection microscope after scarification to ensure that only the seed coat was disrupted. All seeds were then placed in petri dishes (Figure 4).



Figure 4. Germinated seedlings in a petri dish on wet filter paper.

Each petri dish contained three sheets of filter papers, which were thoroughly soaked and rinsed with distilled water. After seeds were placed in the petri dishes on a wet surface of the filter paper, the petri dishes were put in a Conviron growth chamber. Day/night temperature was set at 25/15°C and photosynthetic active radiation (PAR) was set at $50\mu\text{mol m}^{-2} \text{ s}^{-1}$ above the surface of the petri dishes. The filter paper in the petri dishes was kept moist by adding distilled water (enough distilled water to create a meniscus level with the bottom of the seeds). After 71 hr in the Conviron growth chamber, 94% of the seeds germinated with emergent cotyledons. After the first leaf (with 3 leaflets) emerged, the seedlings were transplanted into one of 15 plastic containers (35x35x10 cm), which were filled with a mixture of desert soil and Vermiculite (Figure 5).



Figure 5. The seedlings were transplanted into plastic containers.

Desert soil from the general vicinity of the milkvetch sites (from the same geological formation and with a similar soil texture) was brought to the laboratory at UCLA and mixed with Vermiculite (50% desert soil and 50% Vermiculite) to increase soil aeration.

After transplanting, the plastic containers were placed in the Conviron growth chamber for 4-6 days until the seedlings had recovered from transplanting (indicated by new growth). The plastic containers were then placed in a greenhouse at UCLA. For simplicity and to reduce extra variables, the day/night temperature in the glasshouse was set to 23/18°C in April and increased to a maximum of 33/22°C in June and July.

Relative humidity (RH) was 40 – 65% during spring and 35 – 45% during summer. The maximum midday PAR (photosynthetic active radiation) in the glasshouse during the experiment was $1500 \mu\text{mol m}^{-2} \text{s}^{-1}$ and the mean daily PAR in the glasshouse during the experiment was $30 \text{ mol m}^{-2} \text{ d}^{-1}$.

When the seedlings had recovered from transplanting (indicated by new growth) in the growth chamber, the plastic containers were then moved to the greenhouse at UCLA, which was set to a day/night temperature of 23/18°C. Each seedling, when it was about

5-9 cm in height, was transplanted to a 4 inch diameter \times 36 inch long PVC pipe, and was now set for testing the effect of frequency and amount of precipitation on seedling survival. The experiment was divided into three phases: watering, drought, and watering and received one of nine different watering treatments [three different amounts of water \times 3 different frequencies (Figure 7)]. Each treatment was performed on 5 seedlings and was replicated 3 times. The watering amount for each treatment is tabulated in Table 1 below.



Figure 6. Sample pvc tubes. After the seedlings in plastic containers reached about 5-9 cm in height, each seedling was transplanted to a 4 inch diameter \times 36 inch long PVC pipes.

Watering Experiment (Greenhouse Study)

After the seedlings in the plastic containers (35x35x10 cm) reached about 5-9 cm in height, each seedling was transplanted to a 4 inch diameter \times 36 inch long PVC pipes (Figure 6).

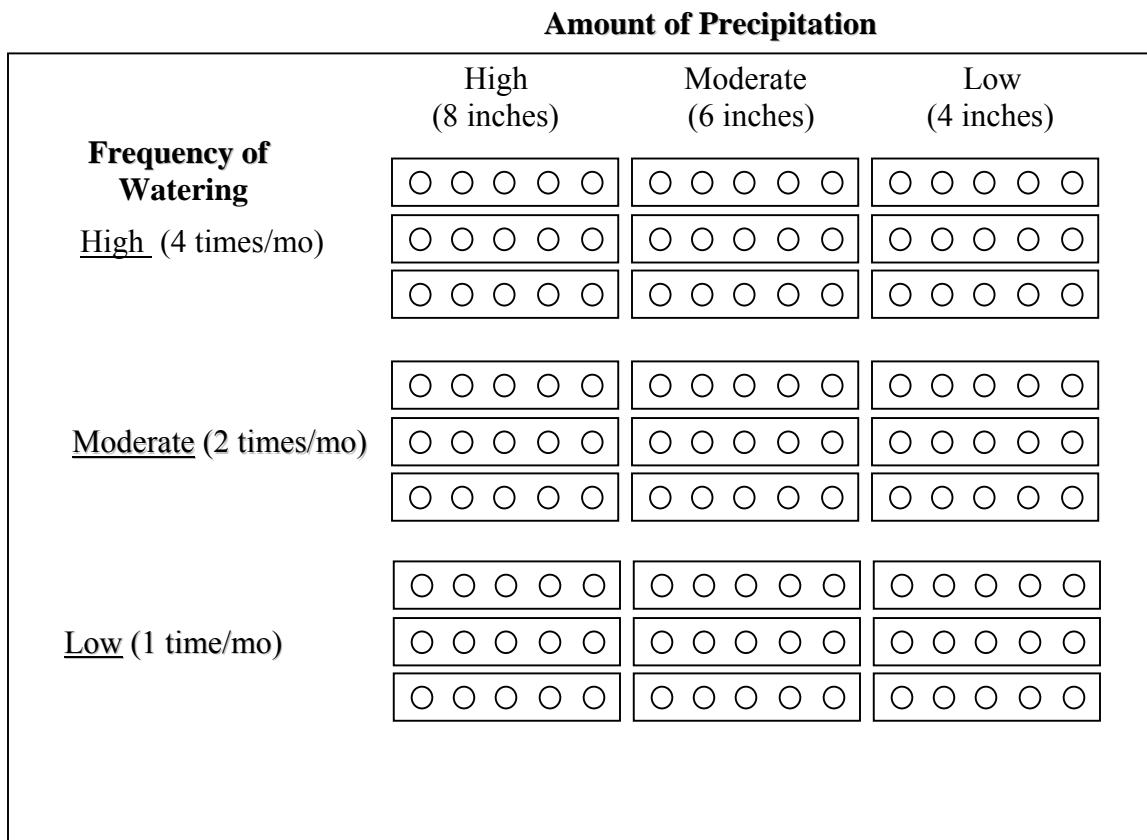


Figure 7. Diagram of watering treatments, each block is one replicate of one treatment and each circle is one plant.

Table 1. Amounts and frequency of watering per treatment.

		Total amount of precipitation over 6 months		
Watering frequency per month	$4" = 101.6 \text{ mm}$ or 834 cc per 4" diameter pipe	$6" = 152.4 \text{ mm}$ or 1236 cc per 4" diameter pipe	$8" = 203.2 \text{ mm}$ or 1647 cc per 4" diameter pipe	
Amount per treatment				
1	139 cc	206 cc	275 cc	
2	69 cc	103 cc	137 cc	
4	34 cc	51 cc	69 cc	

The PVC pipes were filled with desert soil. As described above, desert soil from the general vicinity of the milkvetch sites (with a similar texture to the soil of milkvetch

habitats) was brought to the laboratory at UCLA and was sieved (with a 5mm mesh sieve) to remove gravel (particles larger than 5mm in diameter) and other organic particles, such as leaves, shoots and roots. Thus the growing medium was a mixture of sand and small gravel (smaller than 5mm in diameter), which mimics the colluvial substrate of the milkvetch sites and has good aeration and drainage properties. The PVC pipes were placed in the greenhouse at UCLA. The day/night temperature and other environmental conditions in the greenhouse were as described above.

The initial amount of watering was 1 inch, to insure the survival of transplants which is generally considered enough to trigger seed germination and new growth, but subsequent watering was at one of three levels: 4, 6, or 8 inches per growing season, where the growing season for this experiment was 6 months (the approximate time from seed germination to the end of growing season for the milkvetch).

A 1/5th strength Hoagland's (Hoagland and Arnon 1950) solution was incorporated into the water treatments to avoid nutrient deficiency. All the experiments were conducted in a temperature controlled glasshouse at the University of California, Los Angeles (UCLA). After the seedlings exceeded 15-20 cm height, they were supported with dead tumbleweed branches to provide trellis-like support that would normally be provided by the canopy of the nurse plant.

Seedling demography and phenological measurements

Five days after transplanting the seedlings to PVC pots, we began our qualitative and quantitative phenological observations on all milkvetch seedlings. Our phenological observations included the measurement of the leading shoot length; total shoot length (main shoot + lateral shoots), leaf growth, and flower and pod production. Weekly rates of leading shoot elongation rate were calculated from the weekly measurements.

Photosynthesis measurements:

To avoid any disturbance and damage caused by handling the experimental plants, only a limited numbers of gas exchange measurements during the peak growth period were taken. To understand the effects of different water supply conditions on physiological

performance, gas exchange measurements were made on leafy shoots of the plants under different treatments. Photosynthesis (gas exchange) measurements (the net CO₂ uptake and transpiration water loss of the leaves) provide the most sensitive method available to assess the physiological activity and health of a plant under water stress or other environmental stress conditions. A portable gas exchange system (LI6400, LI-COR Inc., Lincoln, Nebraska) capable of maintaining steady-state conditions with respect to temperature, CO₂, and water vapor concentrations within the assimilation chamber were used to measure these parameters. Net CO₂ uptake (A), stomatal conductance to water vapor (g) and transpiration (E) were monitored on selected mature study plants during the peak growth period. This procedure was nondestructive, because the leaf area was determined by tracing the measured leaf.

Statistical analysis

Growth of Lane Mountain Milkvetch in the different watering regimes was analyzed with a two-factor ANOVA (Statview). One factor was watering frequency and the other was amount of water. Because of mortality, which resulted in unequal sample size, the effect of precipitation amount and frequency on seedling survival after the summer drought were analyzed independently with a one-factor ANOVA (Statview). Statistical analyses of Net CO₂ uptake (A), transpiration (E) and water use efficiency (A/E) were also analyzed with one-factor ANOVA.

Field Study

Population Demography

We conducted several site visits to our permanent survey plots (Montana Mine, site 1 along the Brinkman Wash Road and Goldstone, site 6, Figure 1). The Montana Mine site was first surveyed in 1999, and the Goldstone site was first surveyed in 2003.

The high precipitation frequency and above average precipitation amount of 2004-2005 rain-year were expected to stimulate massive seed germination and seedling establishment of milkvetch in milkvetch sites at the Mojave Desert.

During this project the Montana Mine site was surveyed on December 15, 2004; January 27, April 1, October 15, 2005, March 1, April 28, 2006 and the Goldstone site on January 26, March 31, and June 4, 2005, and March 2, April 29, 2006. Our effort during these

surveys was focused on relocating previously tagged plants, finding new plants, searching for seedlings under and around nurse planst and the LMMV plants of the previously tagged plant.

Relocated and newly found mature plants were evaluated for the following parameters:

- resprouted or not
- vegetative growth in terms of longest shoot,
- damage from herbivory: rabbits/hares, other mammalian herbivores, aphids, etc.
- Reproductive output: number for flower buds, flowers, and fruits produced.

For plants with modest flowering and fruiting, the flowers and fruits were counted, and for plants with heavy flowering, the inflorescences were counted and multiplied by an estimate of the average number of flowers or fruits per inflorescence.

All seedlings found were marked with a 4 inch wooded stick (coded with rings drawn by a marking pen) and their phenological progress was monitored on subsequent surveys.

The vegetative parameters measured were:

- Shoot length
- Leaf number (for plants with < 20 leaves)
- Leaflet number (for plants with < 20 leaves)
- Herbivory

For all the seedlings and tagged milkvetch plants found, we recorded the UTM coordinates using a global positioning system (GPS) unit and updated our readings of previous years for accuracy.

Precipitation Data

We obtained precipitation data for the Goldstone Echo No. 2 and Barstow weather stations from the National Oceanic and Atmospheric Administration's web site:

<http://www.ncdc.noaa.gov/oa/climate/stationlocator.html>

and for Goldstone and TA Bravo remote weather stations from Brian Shomo at the Directorate of Public Works, Fort Irwin NTC (DPW). Recent data and mapped locations

of the weather stations were available (apparently no longer maintained?) from the Handar web site:

http://www.irwin.army.mil/weather/weather/Remote_Sensors/Range%20Remote%20Sensing.htm

The closest weather stations to our sites range from 4.8 km (Goldstone Echo No. 2–Site 6) to 8.6 km (Goldstone and TA Bravo–Site 1).

For Goldstone Echo No. 2, the average annual values for precipitation are based on the precipitation year (July 1 to June 30) for the fourteen year period from July 1, 1990 to June 30, 2004, except the precipitation year 2002–2003 was not included in the calculation because of missing data.

The missing precipitation data from the Goldstone Echo No. 2 (September 2002 to July 2003) is unfortunate, but data from other stations were used to fill in the missing values for this period. The Goldstone and TA Bravo stations supplied the missing monthly precipitation totals, and the daily data from the Barstow station indicated the dates and the number of storm events.

At this time the data for 2005 has not been reported for the last few months, and the TA Bravo station was out of service for a short time because of the heavy rain in spring 2005.

RESULTS AND DISCUSSION

Watering experiments (Greenhouse study)

Leading shoot length

The shoot length growth of the LMMV within the 8" precipitation treatment was significantly greater in the high frequency watering (4 times per month, hereafter 4×/month) treatment than two times per month (hereafter 2×/month) and one time per month (hereafter 1×/month, Figure 8, 9 and 10). The shoot growth activity of 8" rain and high frequency watering (4×/month) showed continued growth throughout the duration of the experiment and reaching a maximum length of 32 cm. However, growth activity of 8" rain and medium frequency watering (2×/month) treatment and one time per month (1×/month) treatment reached their maximum length after about the 11th and 6th weeks

respectively. The 1× treatment showed slight growth that leveled off at about 14 cm long. The amount and frequency of watering regime caused significant differences (for frequency, $F = 6.05$; $P = 0.003$ and for amount of rain, $F = 39$; $P < 0.001$) in shoot length between the different watering treatments (see appendix 1a, statistical analysis).

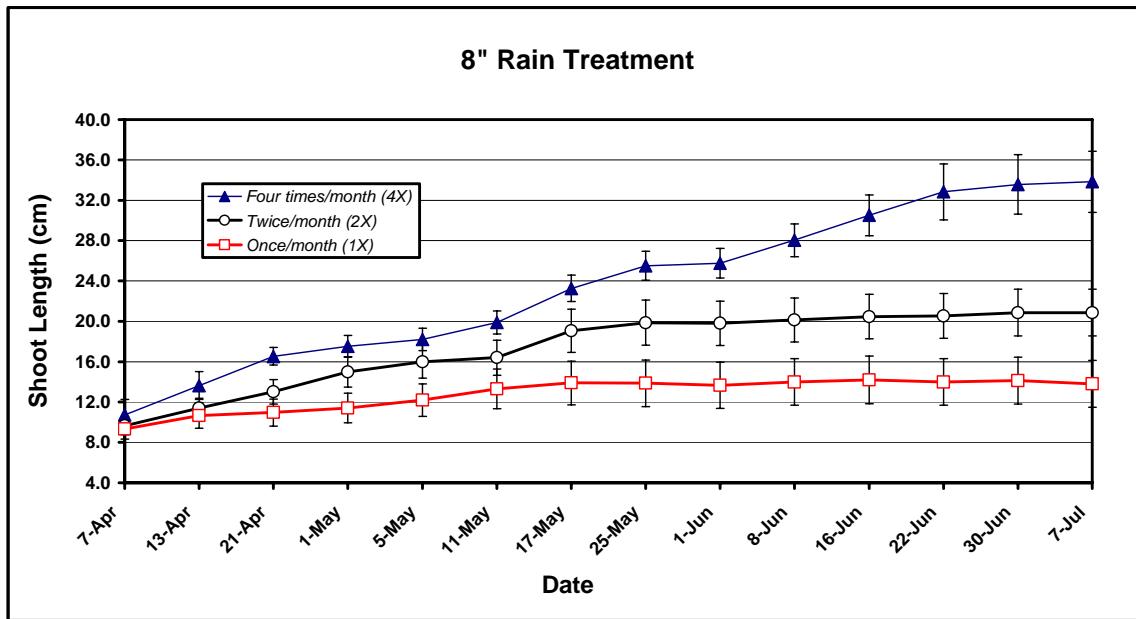


Figure 8. Average Milkvetch shoot length ($n=15$) for 8" rain treatment for different watering frequencies during 2006 growing season at UCLA glasshouse. Error bar = 1 standard deviation.

The LMMV seedlings, which received 6" precipitation, showed slower growth activity than 8" treatments and reached their maximum length after about 7 weeks. Overall, the 4× treatment had the highest average leading shoot length, followed by the 1× and 2× treatments respectively (Figure 9).

All the seedlings from the low watering treatments (4" rain) reached maximum growth after three weeks of planting. There were no significant differences in leading shoot length between the different watering frequencies within the 4" precipitation treatments. Overall, the 1× treatment showed the highest leading shoot length at about 9 cm compared to the ~7.5 cm exhibited by the 4× and 2× treatments (Figure 10) and suggests that the small amounts of water administered at 2× and 4× are insufficient.

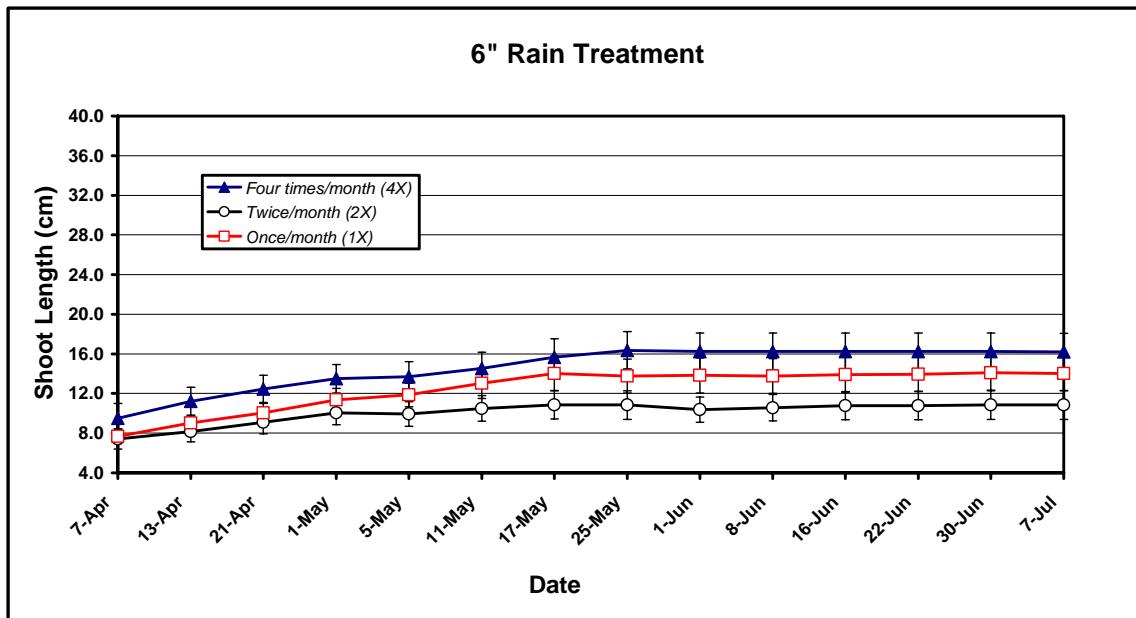


Figure 9. Average Milkvetch shoot length (n=15) for 6" rain treatment for different watering Frequencies during 2006 growing season at UCLA glasshouse. Error bar = 1 standard deviation.

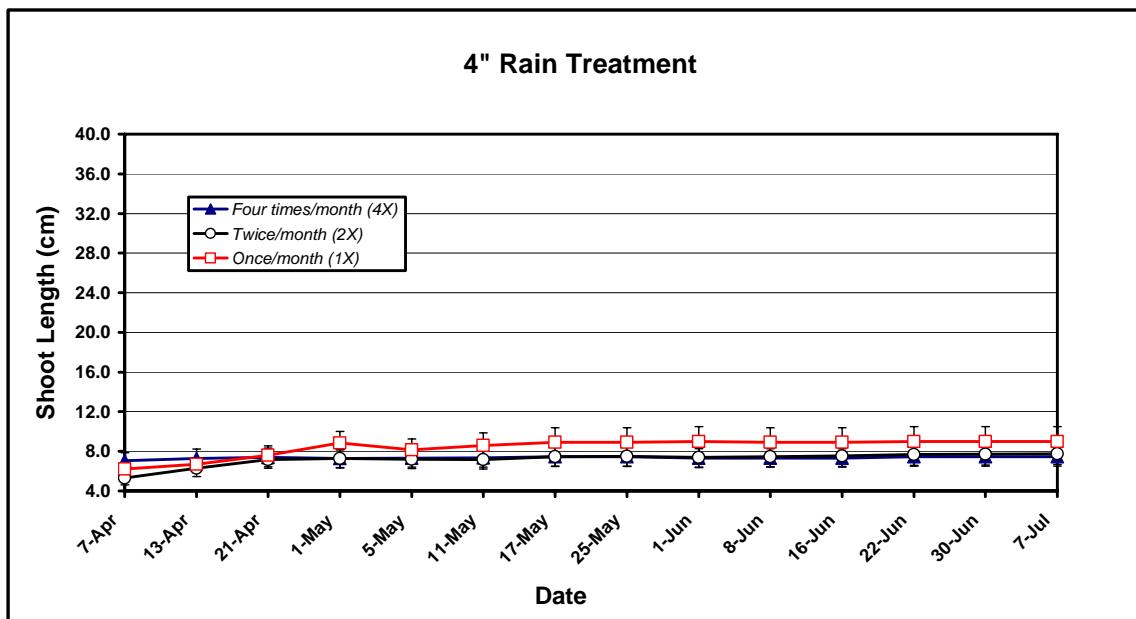


Figure 10. Average Milkvetch shoot length (n=15) for 4" rain treatment for different watering frequencies during 2006 growing season at UCLA glasshouse. Error bar = 1 standard deviation.

Seedlings receiving 1×/month water within the 6" precipitation treatment showed higher leading shoot growth than 2×/month watering frequency. The amount of water (206cc) in

1×/month watering frequency was large enough to penetrate deeper in the soil profile of the PVC pipes and subsequently would keep the root medium wet for a longer period. However the amount of water (103cc) in 2×/month watering frequency was not large enough to penetrate deep in the PVC pipes and subsequently the soil in the pipes dries out faster (through surface evaporation and root absorption) than the 1×/month watering frequency. This factor was even more pronounced during late spring and summer where high daytime temperature in the greenhouse caused high rate of evaporative water loss from the soil surface and subsequently high water stress.

Seedlings receiving 1×/month water (137cc) within the 4" precipitation treatment showed highest leading shoot growth (but not significant) than 2×/month (69cc) and 4×/month (34cc) water. The amount of water (137cc) in 1×/month watering frequency was large enough to penetrate deeper in the soil during spring than 2×/month (69cc) and 4×/month (34cc).

We found large variations in seedlings growth within the 8" precipitation treatment and within each watering frequency between the different seedlings. The height of the seedlings during the peak growth period ranged from 25–41 cm, 17-25cm and 8-15cm for 4×/month, 2×/month and 1×/month respectively.

The interaction of amount and watering frequency is depicted in Figures 11, 12 and 13. While high amount of precipitation (8") caused significantly greater shoot growth in high (4×/month) and moderate (2×/month) watering frequency than the moderate (6") and low (4") amount of precipitation (Figures 11 and 12), in low watering frequency treatment, there was no difference in shoot growth between the high amount of precipitation (8") and the moderate amount of precipitation (6"), (Figure 13.)

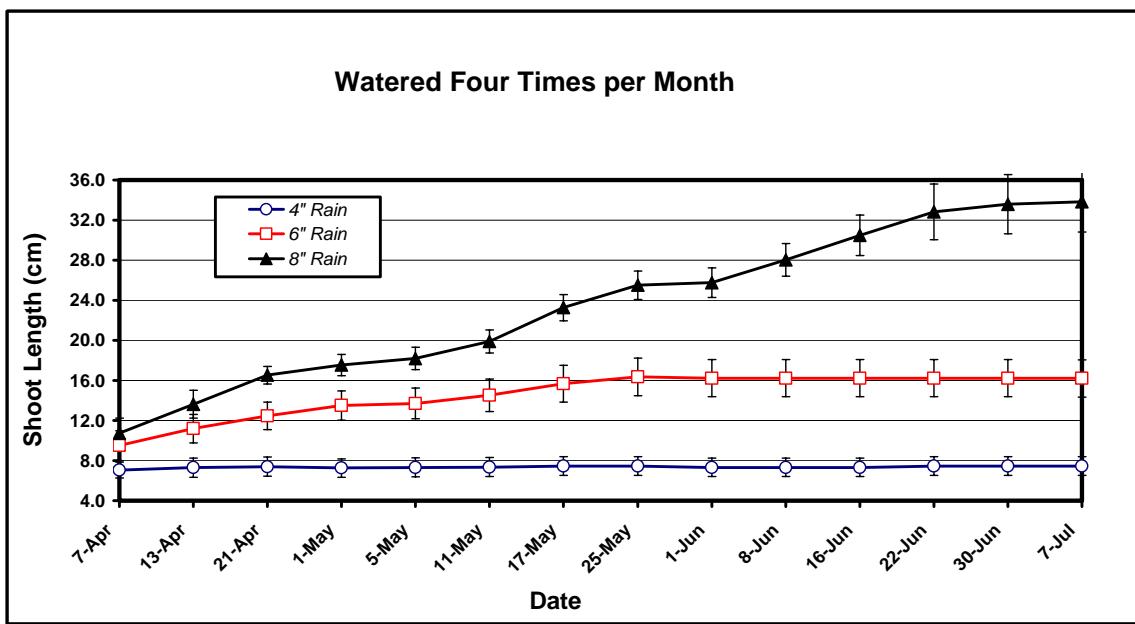


Figure 11. Average shoot length (n=15) of Milkvetch plants watered four times per month (4×/month) for varying rain treatments (4", 6", and 8" Rain) during 2006 growing season at UCLA glasshouse. Error bar = 1 standard deviation.

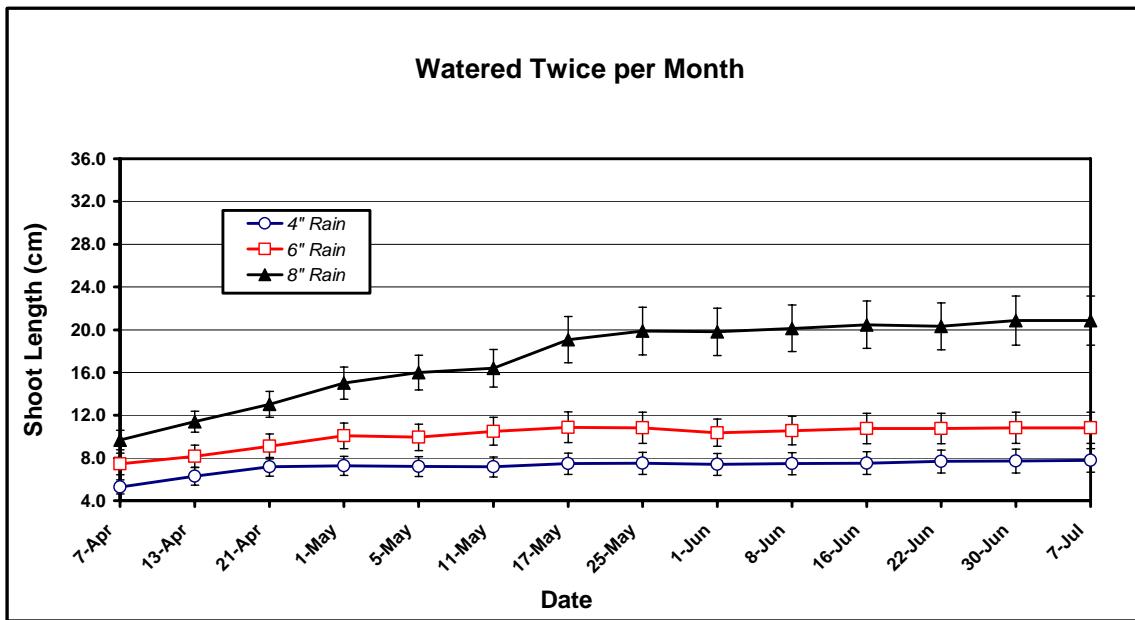


Figure 12. Average shoot length (n=15) of Milkvetch plants watered two times per month (2×/month) for varying rain treatments (4", 6", and 8" Rain) during 2006 growing season at UCLA glasshouse. Error bar = 1 standard deviation.

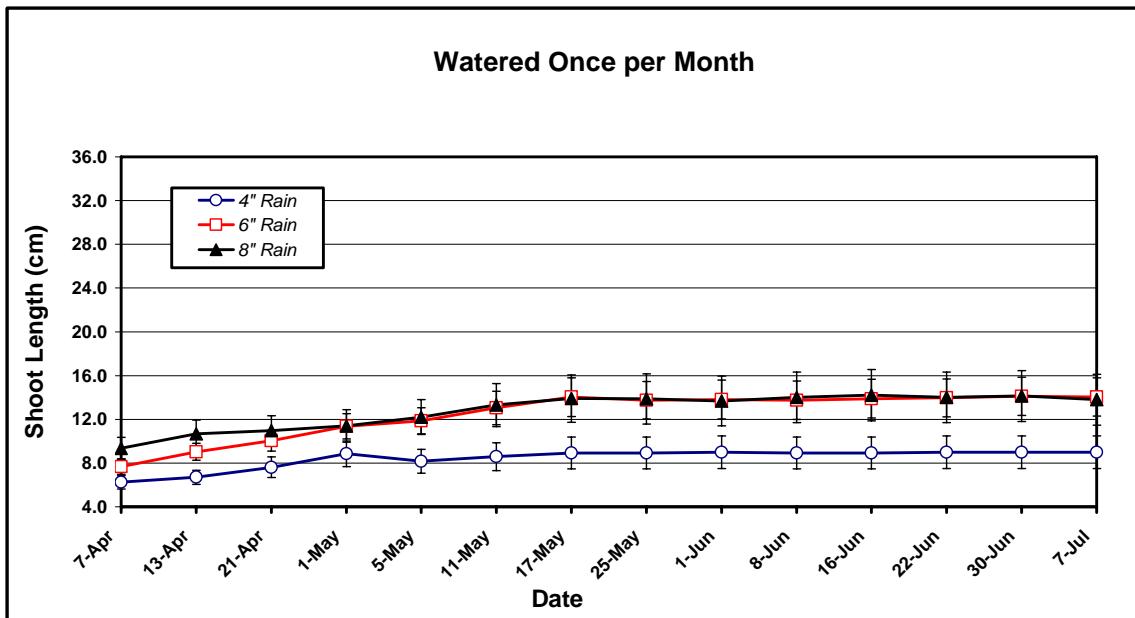


Figure 13. Average shoot length ($n=15$) of Milkvetch plants watered one time per month ($1\times/\text{month}$) for varying rain treatments (4", 6", and 8" Rain) during 2006 growing season at UCLA glasshouse. Error bar = 1 standard deviation.

The two-factor ANOVA showed that both factors (frequency and amount) had significant effects on the shoot length of LMMV (for frequency, $F = 6.05$, $p = 0.003$; and for Amount of rain, $F = 39$, $p << 0.001$).

Shoot elongation rate

The 8" precipitation treatment showed the most continued growth throughout the course of the experiment. Maximum growth rates for the 4 \times and 2 \times treatments occurred during the week of May 25, whereas maximum growth for the 1 \times treatment occurred within the first week. After May 25, there was minimal growth for the 2 \times and 1 \times treatments, whereas the 4 \times treatment maintained a steady growth rate through the end of growth season (Figure.14, 15 and 16).

Within the 6" precipitation treatment, all watering frequency showed maximum growth during the 1st week of the experiment. All three watering frequencies (4 \times/month , 2 \times/month and 1 \times/month) showed continued growth up until May 25th, and shoot

elongation rate continued thereafter but was minimal, less than 0.5 mm per day (Figure 15).

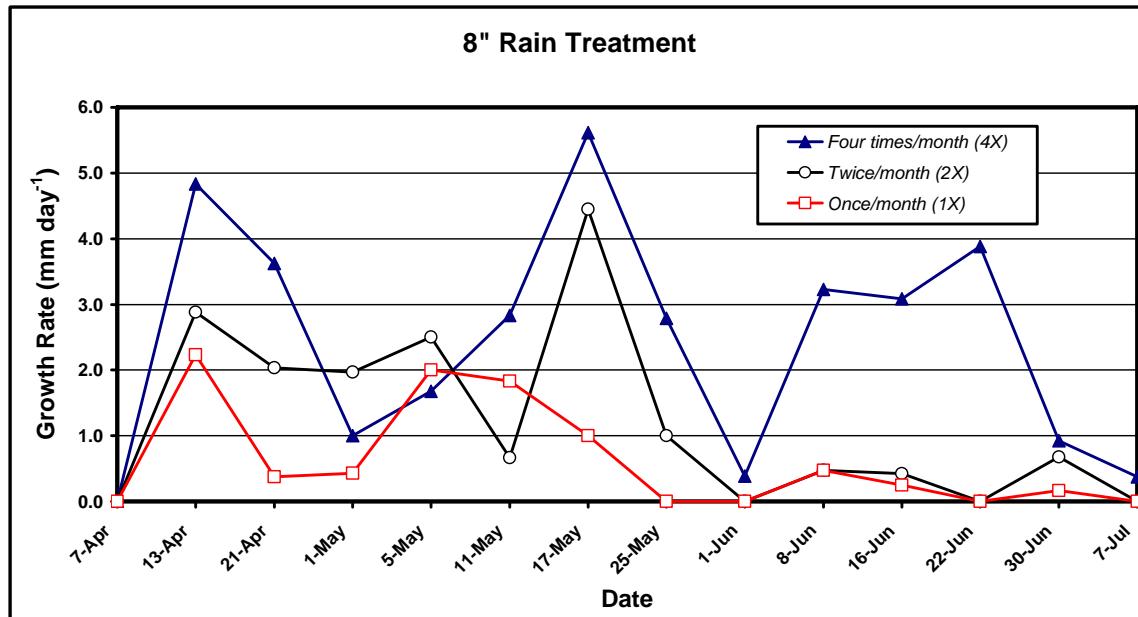


Figure 14. Milkvetch leading shoot elongation rate for 8" rain treatment during 2006 growing season at UCLA glasshouse.

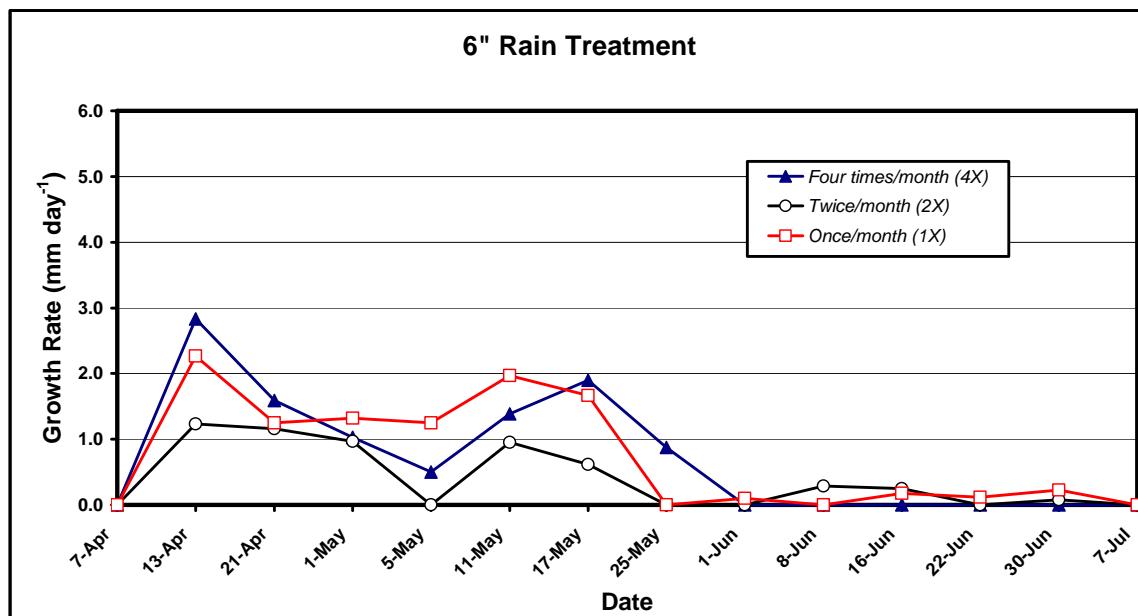


Figure 15. Milkvetch leading shoot elongation rate for 6" rain treatment during 2006 growing season at UCLA glasshouse.

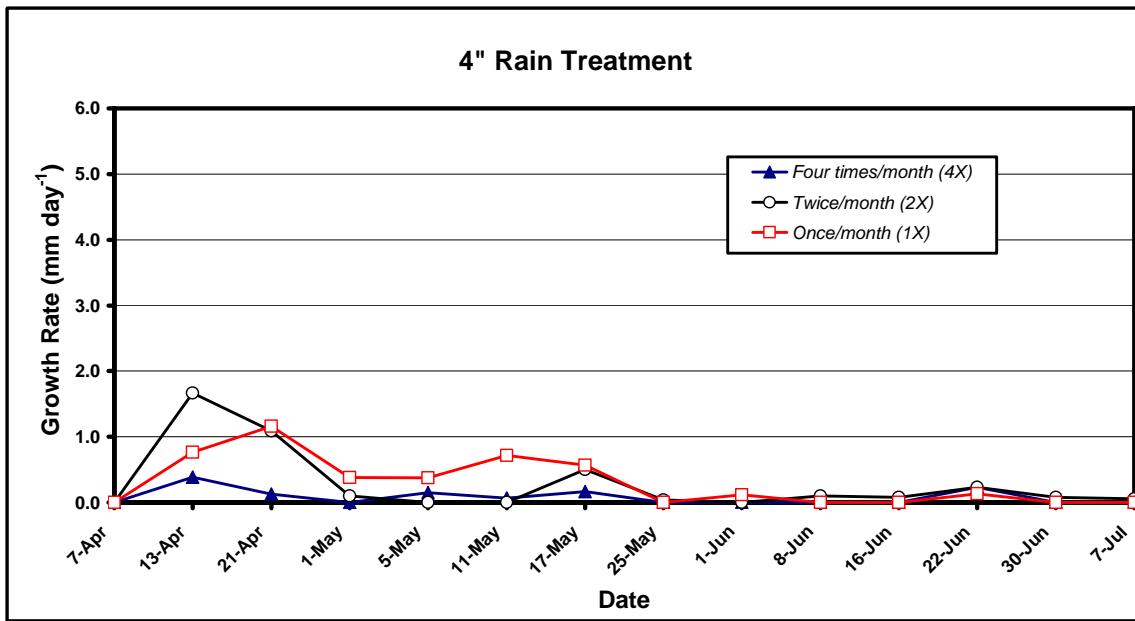


Figure 16. Milkvetch leading shoot elongation rate for 4" rain treatment during 2006 growing season at UCLA glasshouse.

The maximum growth rates for each of the watering frequency within the 4" precipitation treatment occurred within the first two weeks of the experiment. Thereafter, growth continued but at staggered rates and very low (Figure 16).

The growth rate of the leading shoots of Lane Mountain milkvetch (LMMV) was the highest (5.5 mm day^{-1}) for the high precipitation (8") and high watering frequency (4×/month). High precipitation (8") treatment, together with high watering frequency (4×/month) had a significant effect on LMMV shoot growth rate. Shoot growth was slow during the early stages after transplanting and it is assumed that the LMMV plant allocate most of its initial photosynthetic carbon gain to root production, although no measurements on root growth were taken. In the desert, a strategy of developing an extensive or deep root system would ensure that adequate water could be extracted from the substrates when soils surface begin to dry out.

Total shoot length

Another nondestructive method to evaluate plant growth activity is to measure the total length of the lateral shoots of a plant canopy. We measured the total lateral shoots during the peak growth period (the time when leading shoot did show any elongation), before

the leaves and stems started to become senescence. The amount and frequency of watering regime caused significant differences (for frequency, $F = 7.06$; $P = 0.001$ and for amount of rain, $F = 49$; $P < 0.001$, compare appendix 1b) in total shoot length between the different watering treatments (figure 17 and 18). The highest total shoot length (92cm) achieved by the 8" rain and 4× watering per month and the 4" rain and 4× watering per month treatment had the lowest (7.5cm) total shoot length. No significant difference in the total shoots length between 4" and 6" precipitation. Significant difference in the total shoots length between 4" and 8" and between 6" and 8" precipitation. No significant difference was found in the total shoot length between watering frequency of 1× and 2×/month. A significant difference was found in the total shoot length between watering frequency of 1× and 4×/month and between 2× and 4×/month (see more detail statistical analysis in Appendix 1b).

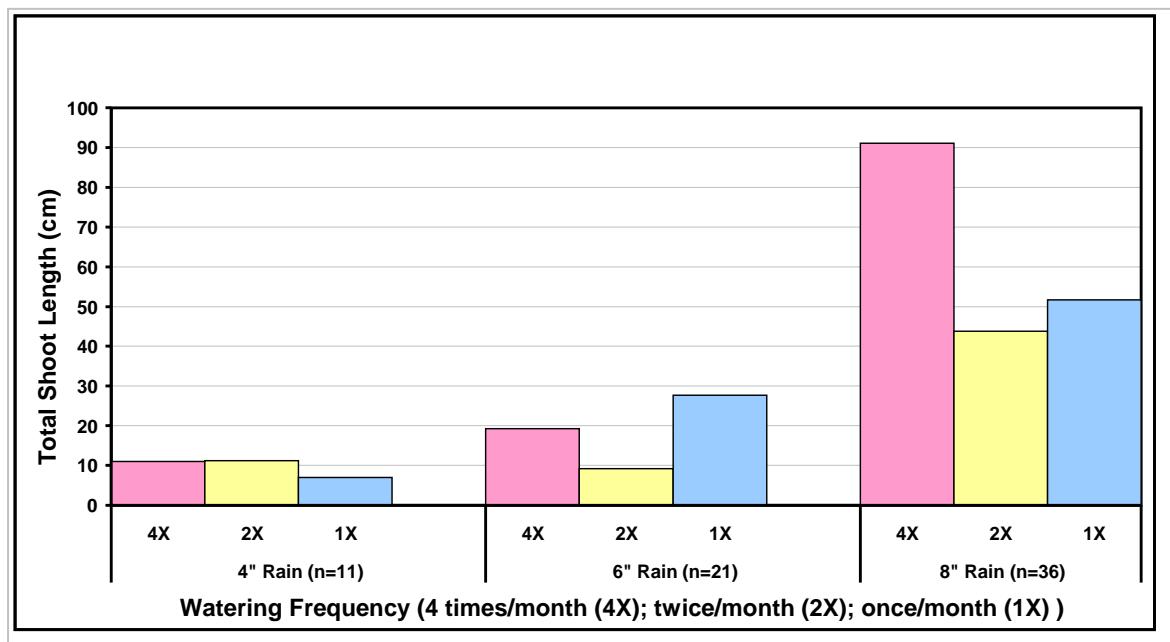


Figure 17. Average total shoot length (leading shoot and lateral shoots) for varying watering frequencies in 4", 6" and 8" rain treatments (n =number of plants). The measurements were taken during the peak growth period.

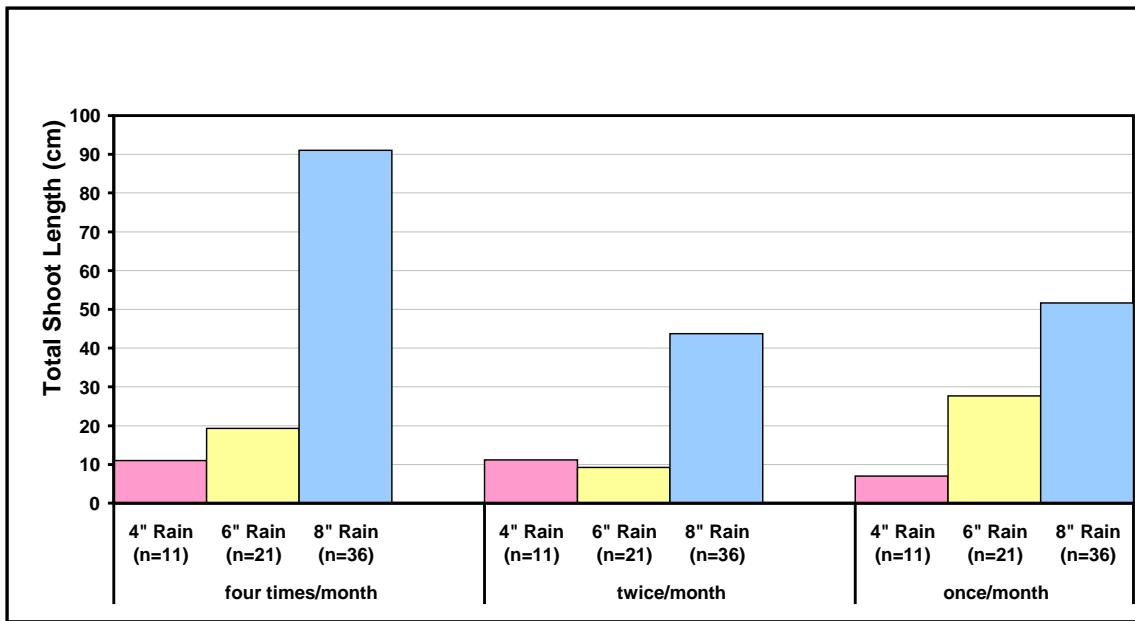


Figure 18. Average total shoot length (leading shoot and lateral shoots) for varying rain treatments in 3 different watering frequencies (n=number of plants). The measurements were taken during the peak growth period.

Seedlings mortality

The highest mortality occurred (100%) with the 4 inch precipitation treatment for all three precipitation frequencies (4 times per week, 2 times per week and one time per week, Figure 19). The 8 inch precipitation treatment at the highest frequency (4 rain events per week) had the lowest mortality, and the intermediate frequency (2 times per week) had the second lowest mortality.

There were highly significant differences between the watering frequencies within 8" precipitation treatment, with the highest mortality (68%) reaching once per month watering frequency (appendix 1c). Both factors (the amount of precipitation and frequency) have a significant affect on the number of seedlings that survived to July. The more water the greater the survival; the greater the frequency, the greater the survival. Interaction of amount of precipitation and frequency also was significant. More frequent watering increasing the affect of total precipitation, at least at 8" precipitation, (see appendix 1c the statistical analysis).

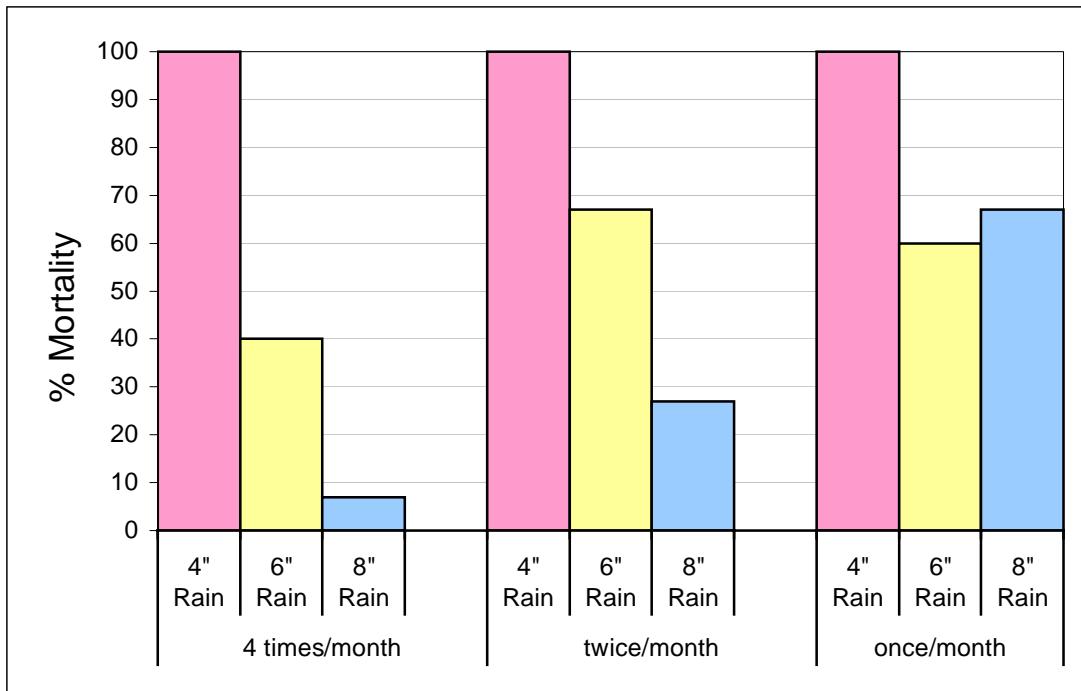


Figure 19. Comparison of percentage mortality between the Lane Mountain Milkvetch seedlings for different treatments on 7/7/2006 (peak growth).

Physiological responses to the frequency of precipitation

Water is one of the major limiting factors for seedling growth and survival to a mature plant in all desert ecosystems. Our previous field studies during *El Niño* of 2002-2003 indicated that not only the amount, but also the frequency of precipitation is crucial in maintaining a sustainable population of the LMMV in the central Mojave Desert (Rundel, Sharifi and Prigge 2005). In this study we examined the response of the photosynthetic CO_2 uptake of the LMMV to 8" rain (which is equivalent to a *El Niño* year) three different frequencies. The photosynthetic capacity (as measured $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) and transpiration (as measured $\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$) of LMMV had significantly increased with the increasing of the frequency of precipitation (Figure 20, 21, Appendix 1d and 1e respectively). Water use efficiency (WUE) measured as the ratio of $\mu\text{mol CO}_2$ uptake per m^{-2} of leaf per s^{-1} ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) and $\text{mmol transpiration per m}^{-2}$ of leaf per s^{-1} ($\text{mmol m}^{-2} \text{ s}^{-1}$), had significantly decreased with increasing frequency of the precipitation (Figure 22 and Appendix 1f).

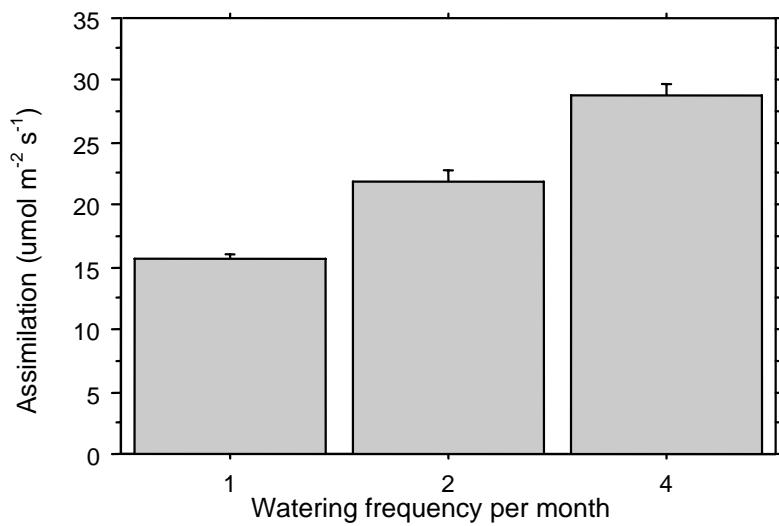


Figure 20. Effect of watering frequency at 8" precipitation on photosynthetic capacity (P_{\max}). Error bar = ± 1 standard deviation.

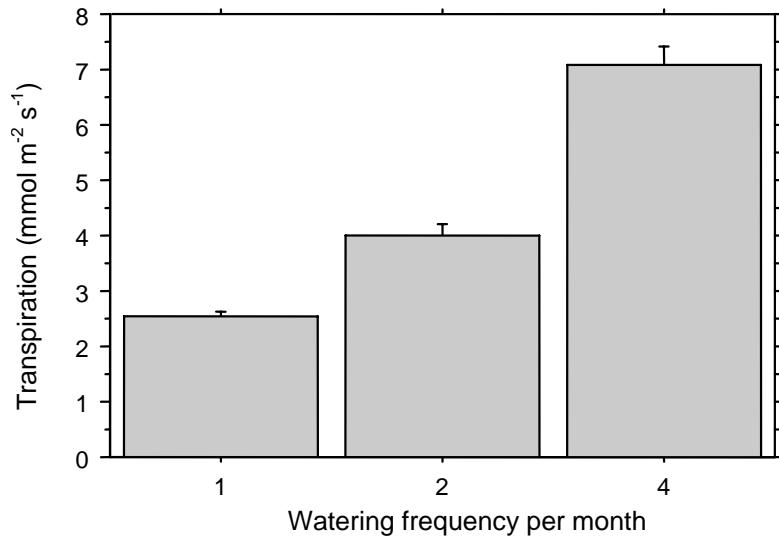


Figure 21. Effect of watering frequency at 8" precipitation on transpiration rate. Error bar = ± 1 standard deviation.

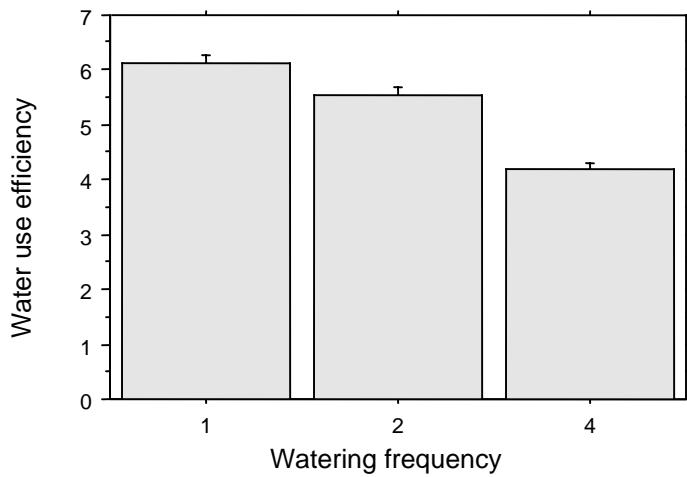


Figure 22. Effect of watering frequency at 8" precipitation on water use efficiency (WUE). Error bar = ± 1 standard deviation.

Resprouting after summer dormancy

We stopped watering the plants after July 15, 2006 for three months (July – October), to determine if the plants were mature enough to survive a summer drought and would have enough carbon stored in the roots to resprout, similar to the LMMV plants under the field condition. One week after resumption of watering the 33% of the plants from the 8" rain with 4× watering frequencies per month and 7% of the 8" rain with 2× watering frequencies per month resprouted (Table 2). Because so many seedlings did not survive to July and the unequal sample sizes, a 2-factor ANOVA was not possible. The amount of precipitation and frequency of watering had to be analyzed separately. The analysis was based on only the seedlings ($n = 46$) that were alive in July (appendix 1g and 1h). The amount of precipitation significantly affected ability of plants to resprout, presumably because plants under higher amount of precipitation developed greater root mass to endure a long drought.

All the resprouted individuals indicated a healthy and vigorous growth (Table 3 and figure 23), however there were large variations in vegetative and reproductive growth between

the different individuals. Four individuals produced flowers and only one plant produced pods.

Table 2. Percentage of resprouted LMMV plants for varying treatments.

Precipitation Amount	Frequency of watering	% resprouted
8 inches	4×*	33
	2×	7
	1×	0
6 inches	4×	0
	2×	0
	1×	0
4 inches	4×	0
	2×	0
	1×	0

* times per month

Table 3. Phenological development of the resprouted LMMV plants grown at UCLA greenhouse (data taken on 11/02/06).

Plant ID	Basal diameter (mm)	Leading shoot length (cm)	Number of flowers	Number of pods
8-2-9	2.60	107	0	0
8-4-1	2.77	118	10	0
8-4-5	3.82	126	50	0
8-4-6	2.88	91	306	23
8-4-7	3.62	127	130	0
8-4-8	3.01	51	0	0



Figure 23. Resprouted LMMV plants in the greenhouse at UCLA (11/10/06).

Field Study

Seedling establishment

The above-average precipitation conditions of 2004-2005 (Figure 3) in the Mojave Desert provided us with a unique opportunity to monitor populations of the Lane Mountain milkvetch for:

- Density of seedlings
- Growth and spatial establishment of seedlings
- Demography: resprouting (survival), herbivory, and demise of existing plants.

Surveys in spring 2005 showed uneven germination between the Montana Mine and Goldstone sites (Table 4 and Figure 24) and that germination was lower than expected given the wet winter conditions. From our model we should have expected 100's of seedlings of which only a small fraction would survive to the next growing season and replace plants that have died since the last time of good establishment.

Of the 14 seedlings that germinated during winter 2004 (with record high precipitation), 12 of them survived the 2005 summer, and only 8 of them survived into the spring 2006. None of these 8 surviving seedling have reproduced (no flower production).

Table 4. Number of seedlings monitored during 2004-2006.

Site		12/15/2004	1/28/2005	4/1/2005	10/15/2005	3/1/2006	4/28/2006
Montana Mine	total number of seedlings	14	16	30	12	11	8
	lost from previous survey	-	2	3	18	1	-
	gained from previous survey	-	4	17	-	-	-
Goldstone	total number of seedlings		8	0	0	0	0

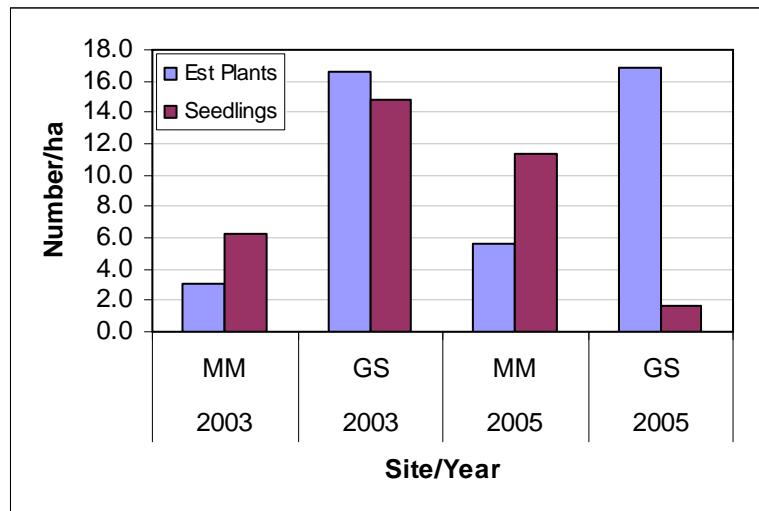


Figure 24. The number seedling compared with established plants (resprouted plants > 1 year old) at Montana Mine (MM) and Goldstone (GS) sites.

Resprouting

In 2005, after several years of declining populations of the LMMV, the population had an increase in the number of vegetatively active plants older than one year from the previous year (Figure 25). Some of the increase was the result of previously tagged plants that were presumed dead resuming active growth after two to three years of dormancy. The rest (9 new plants from Goldstone and 3 new plants from Montana Mine site) was from finding plants for the first time that were presumably dormant for many years or were overlooked, perhaps because of very meager vegetative growth that was difficult to detect within the canopy of the nurse plant. Despite the new finds and the new activity in dormant plants, there were some plants that either had died since the spring of 2004 or were dormant.

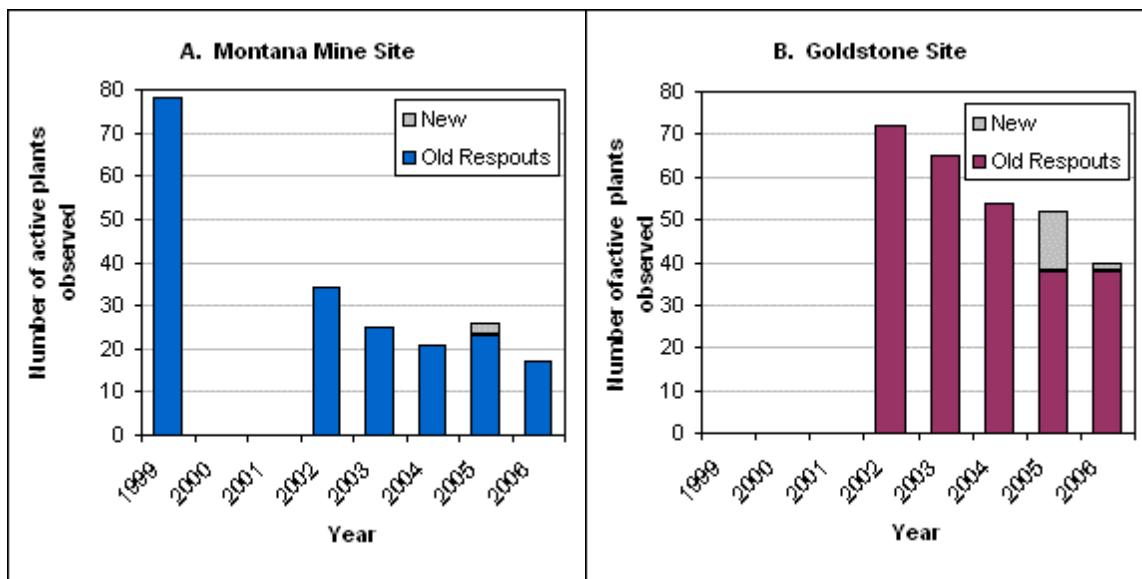


Figure 25. Number of observed active plants > 1 yr old found during surveys from 2003 to 2006 for Montana Mine and Goldstone sites. Old respouts are vegetatively active, previously tagged plants, and “new” are respouts that were not previously tagged and presumably dormant for the last few years. The number for Montana Mine site in 1999 was based partially on our surveys, surveys by Connie Rutherford, and the assumption that anything active in 2003 was probably extant in 1999. The number in 2002 at the Goldstone site is based on the assumption that dead remnants of plants found in 2003 were probably from active plants in the preceding year.

Our survey data values for living LMMV plants for the Montana Mine Site reported here differ slightly from our previously reported values.

Below are the results of our surveys for the Montana Mine site for living LMMV plants. The data values differ from previous reports because:

1. This data is for only the Montana Mine site and does not include other sites along Brinkman Wash.
2. Plants that were presumed dead in one year but were then observed alive in a subsequent year have had their values changed back to “alive or active”. In such cases, we are confident that a seedling did not replace the original plant. The degree of development of the plant (semi woody base) indicates that it was a resprouted from a plant that was previously dormant.
3. The extreme southern part of our extended Montana Mine site has not been surveyed as regularly as it should have been and, therefore, has been excluded

from the data set below.

4. Other miscellaneous errors found in record keeping and some that resulted from confusion over lost field tags have been corrected.

Table 5. Number of living plants of LMMV observed from 1999 to 2006.

Year	1998	1999	2002	2003	2004	2005	2006
plants	0	1	4	5	6	7	8
	80	34	25	21	23	17	

The above data was fitted to an exponential curve and is plotted below in Figure 26. The exponential curve is only slightly better than a linear regression ($r^2 = 0.848$).

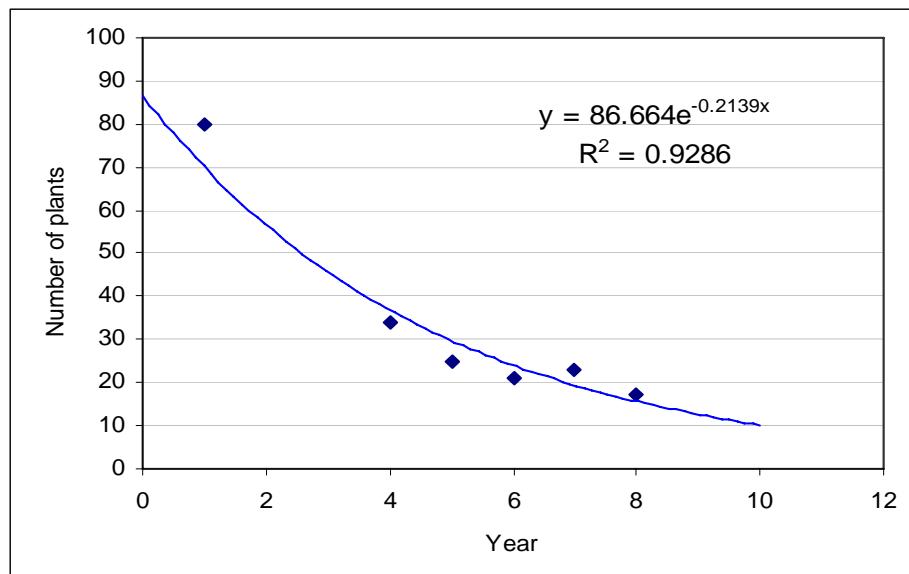


Figure 26. Decline of Milkvetch Populations for the Montana Mine site since 1999.

Assuming that:

1. The above exponential equation applies over the long term, i.e. averages out the variation that results from varying amounts of annual precipitation, temperature, herbivory, disease, etc.
2. Different cohorts have the same rate of loss, i.e. the probability of death is constant through time.
3. The number of seedlings that become established or recruited in a good year is estimated at 60. The 86 in the above equation includes the current year's recruitment + plants from previous cohorts. The recruitment number of 60 is not

unbiased, it was derived by working backwards so that the curve yields results that are close to observed values. It is currently our best guess.

4. Good years occur when ppt > ca 8". There is high germination and seedling establishment.

In the Table 6 below, the populations size through times was calculate for three cohorts by successive calculations of the equation in Figure 26. The total population for:

- Population 1 is computed for the good years (cohorts) of 1992, 1993, and 1998.
- Population 2 is computed for the good years (cohorts) of 1992 and 1998. 1993 is not included based on the possibility that the seed bank was depleted by germination in 1992.

Table 6. Computed population size through time for Population 1 (based on recruitment in 1992, 1993, and 1998) and for Population 2 (based on recruitment in 1992 and 1998). Calculated values are based on equation in Figure 26 where x = year since recruitment.

year	year'	Cohort-92	year"	Cohort-93	year""	Cohort-98	Sum of Cohorts		
							Total Pop1	Total Pop2	Observed
'90							60	60	
'91									
'92	0	60					60	60	
'93	1	48	0	60			108	48	
'94	2	39	1	48			88	39	
'95	3	32	2	39			71	32	
'96	4	26	3	32			57	26	
'97	5	21	4	26			46	21	
'98	6	17	5	21	0	60	97	77	
'99	7	13	6	17	1	48	78	62	80
'00	8	11	7	13	2	39	63	50	
'01	9	9	8	11	3	32	51	40	
'02	10	7	9	9	4	26	41	33	34
'03	11	6	10	7	5	21	33	26	25
'04	12	5	11	6	6	17	27	21	21
'05	13	4	12	5	7	13	22	17	23
'06	14	3	13	4	8	11	18	14	17
'07	15	2	14	3	9	9	14	11	
'08	16	2	15	2	10	7	11	9	
'09	17	2	16	2	11	6	9	7	
'10	18	1	17	2	12	5	7	6	
'11	19	1	18	1	13	4	6	5	
'12	20	1	19	1	14	3	5	4	
'13	21	1	20	1	15	2	4	3	

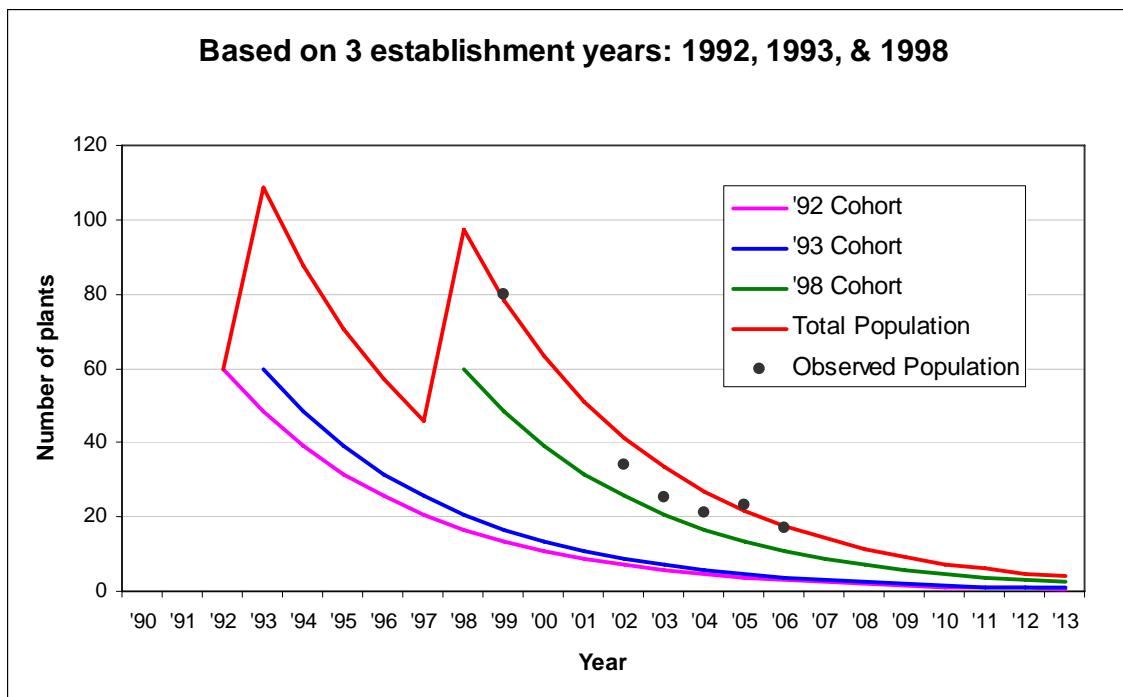


Figure 27. Total Population1 computed for the good years of 1992, 1993, and 1998.

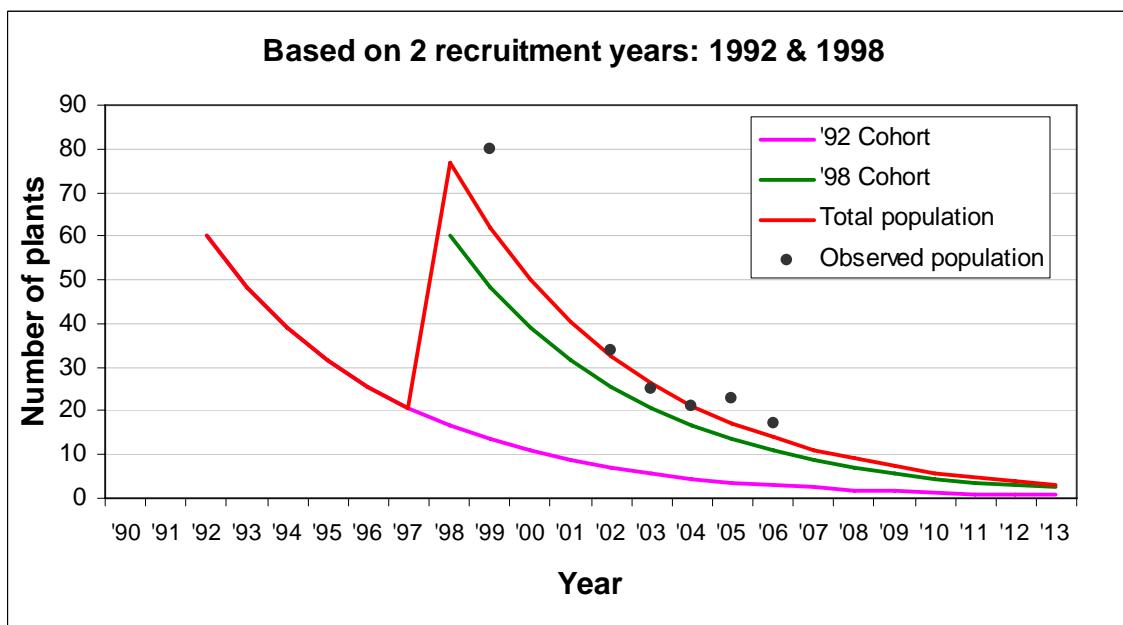


Figure 28. Total Population1 computed for the good years of 1992, 1993 only.

We really have no data to indicate when the establishment years were. Simple precipitation amount does not work very well. Based on ppt, 2004-05 should have been a good germination and recruitment year, but certainly turned out to be a poor recruitment year. Probably because germination and establishment of native annuals and alien annuals was high and they competed with LMMV seedlings. High density of annuals seems to have resulted in high numbers of jackrabbits that in turn probably consumed LMMV seedlings as supported by the evidence of nipped shoots. There are indications that jackrabbits also consumed mature plants. The other causes for a poor establishment could be a) depletion of the soil seed bank through granivory by rodents and birds disease, and seed parasitism by insect and b) spatial and temporal heterogeneity in amount, timing and frequency of precipitation. We found in our lab germination study that 19 - 25% of LMMV seeds were infested with the *Bruchophagus* wasps and inside all the infested seeds were empty. These infested seed were harvested from greenhouse grown plants and as well as from the field.

The results of our glasshouse studies indicate that an 8 inch rainfall with a high frequency of four times per month is optimal for seedling growth and establishment of LMMV. LMMV has a critical lower limit with respect to the amount of precipitation required for seedling survival. In addition our glasshouse studies showed that summer rain is critical for seedlings establishment and survivor to the next spring growing season. Because of the above factors and additional unknown biotic and abiotic factors the number of plants that become established in a good year is speculative, and there is no compelling reason to assume that it is constant. We have yet to observe anything close to 60 established plants.

Reproductive output

The reproductive output as measured as percentage of the number of vegetatively active plants in flower was very high in 2005 (Table 7). Have the active plants all flowered at the Montana Mine site and nearly all flowered at the Goldstone site. This was a considerable increase over the dry year of 2004. In 2003, there were mixed results with high flowering at the Montana Mine site and modest flowering at

Goldstone. The intensity of flowering and fruiting is also important, and these values need to be calculated. Our general observations are that plants on average flowered more profusely in 2005 than in previous years, but in every year there are a few plants that flower profusely and have a high fruit set (ca 70 fruits or more).

Table 7. Percent of active resprouts reproducing (flowering or fruiting) and damaged by herbivory.

Year	Site	Active resprouts	Percent flowering or fruiting	Percent damaged by herbivores
2002-2003	Goldstone	71	34	3
	Montana Mine	12	83	0
2003-2004	Goldstone	60	23	0
	Montana Mine	12	42	0
2004-2005	Goldstone	58	72	36
	Montana Mine	22	86	27
2005-2006	Goldstone	43	2	28
	Montana Mine	17	12	24

PROBLEMS AND PITFALLS WITH HERBIVORES

Aphids and whiteflies have infested the LMMV plants in the greenhouse, but didn't affect the rate of mortality or growth of the seedlings. Moderate numbers of these herbivores were removed by hand or by washing the infected leaves with water. In a few cases we also used mild commercial insecticide to spray the plants.

Granivory: *Bruchophagus* wasp

We found in our lab germination study that 19 - 25% of LMMV seeds were infested with the wasp and inside all the infested seeds were empty. These infested seed were harvested from greenhouse grown plants and as well as from the field.

CONCLUSION

Coordinated studies that incorporate field and laboratory/greenhouse studies facilitate the process of asking pertinent questions and obtaining answers. It would be very difficult to determine the requirements for seed germination in the field without the luxury of controlled environments of the growth chamber, which is able to control for temperature and day/night cycles. It would also be difficult to address the factors that affect seedling survival. Thus, by manipulating the frequency and the amount of precipitation in a greenhouse, we were able to demonstrate that the LMMV seedlings require high frequency (4 times per month) and high amount of precipitation (equivalent to 8" per year) of rain to develop and store enough food reserves in their roots to survive a summer drought of four months and subsequently resprout with the onset of autumn rain.

However, the field studies also demonstrate other important parameters in the LMMV demography/life cycle. The exceptionally wet year, with high frequency of precipitation, in 2004-05 created climatic conditions that was perfect for high germination and growth of non-native annual species and native annual species, both of which seemingly outcompeted LMMV for soil nutrients, soil water, space, and light. These annuals also promoted the growth of the jackrabbit population, which had a negative impact on both mature and seedling LMMV plants.

While field observations led us to speculate on the importance of amount and frequency of precipitation, they, alone, would have remained anecdotal explanations. Our laboratory studies have some crucial numerical and statistical backing to these hypotheses.

RECOMMENDATION

Granivory and seed bank

There is a major problem in the maintenance of a sustainable seed bank, namely, seed loss through granivores, such as *Bruchophagus* wasps species. Female *Bruchophagus* wasps lay eggs in the developing ovary. The eggs hatch inside the mature seeds and the larvae consume the cotyledons inside the seeds. The wasps also infest red clover, alfalfa and other legume seeds. We found that 19 - 25% of LMMV seeds were infested with the

wasp and inside all the infested seeds were empty. These infested seed were harvested from greenhouse grown plants and as well as from the field.

Invasive Species and Fire

Exotic species, such as red brome (*Bromus madritensis*) and cheat grass (*B. tectorum*), *Schismus barbatus*, *S. arabicus* and red stem filaree (*Erodium cicutarium*) have invaded vast areas of the Mojave desert and transformed the vegetation profile of ecosystems at an incredibly rapid pace. The promotion of fire, rapid establishment and competitiveness of these species with native species has dramatically impacted the landscape and the nature of land use. Unlike most native annual plants, which specialize in particular microhabitats, these grasses grow in many different habitats and can create continuous fuel beds across the landscape, filling in the plant-free space that once separated and protected native perennials from fire. Unlike native annuals, which generally deteriorate and blow away soon after they die, dried remains of the nonnative grasses stay rooted often in dense stands, which can be highly flammable for a year or more. They can ignite easily and carry fire rapidly across the landscape.

The recent spread and increased frequency and density of invasive species and the increasing frequency of desert fires raises concerns about the effects these two factors would have on the Lane Mountain Milkvetch. The two factors, invasive species and fire, are not mutually exclusive. Although the frequency and spread of fire is linked with fuel provided by the invasive species, the invasive species also have an effect on competition and may increase herbivory by providing a food source for herbivores (presumably jack rabbits and cottontails) for a longer period and over a greater area. The recent fires during the spring, 2005 in the Mojave National Preserve and in the vicinity of Morongo Valley and Twenty-nine Palms highlight the impending threat that fire poses to the milkvetch habitat.

The role that invasive species, such as red brome (*Bromus madritensis*) and cheat grass (*B. tectorum*), *Schismus barbatus*, *S. arabicus* and red stem filaree (*Erodium cicutarium*), play in competition and in increasing the frequency, intensity, and spread of fire in the milkvetch habitat needs to be studied. Increased herbivore populations supported by the weed flora may affect the milkvetch directly or indirectly through the loss of nurse plants,

which provide structural support and protection from herbivores, and by increased herbivore populations supported by the weed flora. In general, the role that invasive species play, both in competition and in increasing the frequency, intensity, and spread of fire in the milkvetch habitat needs to be studied.

Competition study: Resource competition for water, nutrients and light between fast growing weedy species and milkvetch seedlings was especially strong during 2004-2005 growing season as the increased precipitation of winter 2004-2005 and spring 2005 stimulated unusually vigorous weed growth under and around the milkvetch nurse plant canopy, inhibiting milkvetch seed germination and seedling growth. Even after the unusually wet season of 2004-2005, we thus observed only 49 seedlings and 8 established seedlings in spring 2006.

Long-term field study: A long-term study of milkvetch community demography, soil seed bank dynamics, and restoration is crucial to the understanding of milkvetch community conservation. Understanding the role of milkvetch soil seed bank dynamics in general is vital to milkvetch conservation efforts, and could further serve as a model for the function of seed banks in the population dynamics of other herbaceous perennials (including other endangered species) in desert ecosystems.

Seed dispersal: Determine if rodents, ants, and/or birds disperse seeds. This could be crucial to understanding the distance that seeds are dispersed.

Restoration: Identify suitable sites for restoration and appropriate times for transplanting greenhouse grown plants to the field.

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APPENDICES

Appendix 1: Statistical analysis

Appendix 1a. Two-factor ANOVA analysis for the effect frequency and amount of watering on the leading shoot length of LMMV. Both frequency and amount of watering had significant effects on the shoot length of LMMV. (for frequency, $F = 6.05$, $p = 0.003$; and for Amount of rain, $F = 39$, $p << 0.001$).

ANOVA Table for Height

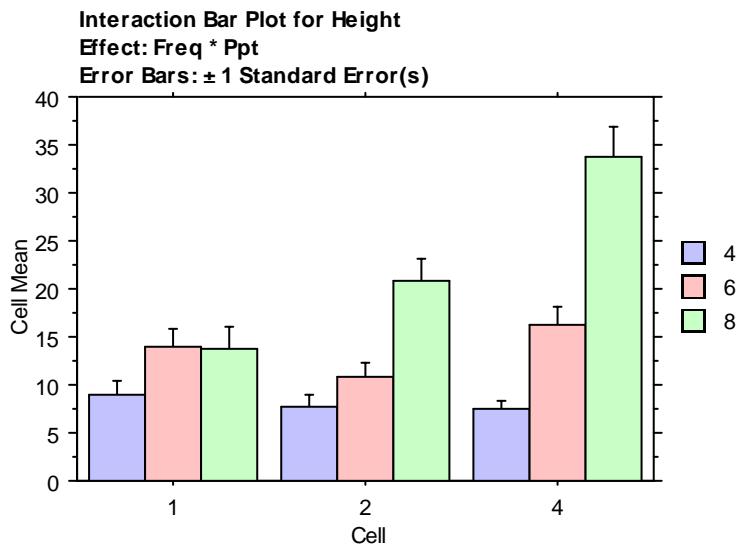
	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Freq	2	1243.667	621.833	11.432	<.0001	22.864	.997
Ppt	2	4887.789	2443.894	44.929	<.0001	89.857	1.000
Freq * Ppt	4	2034.056	508.514	9.349	<.0001	37.394	1.000
Residual	123	6690.599	54.395				

Means Table for Height

Effect: Freq * Ppt

	Count	Mean	Std. Dev.	Std. Err.
1, 4	13	9.000	5.354	1.485
1, 6	14	14.036	6.512	1.740
1, 8	15	13.800	9.002	2.324
2, 4	15	7.767	4.309	1.113
2, 6	15	10.833	5.611	1.449
2, 8	15	20.867	8.895	2.297
4, 4	15	7.467	3.637	.939
4, 6	15	16.200	7.248	1.871
4, 8	15	33.833	11.747	3.033

Frequency/mo (1, 2, 4), Total ppt (4", 6", 8").



Significant interaction. Frequency increases the effectiveness of total ppt, at least for 2x and 4x/month.

Fisher's PLSD for Height

Effect: Freq

Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value
1, 2	-.763	3.132	.6307
1, 4	-6.774	3.132	<.0001
2, 4	-6.011	3.078	.0002

Fisher's PLSD for Height

Effect: Ppt

Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value
4, 6	-5.647	3.131	.0005
4, 8	-14.798	3.113	<.0001
6, 8	-9.152	3.095	<.0001

Appendix 1b. Two-factor ANOVA analysis for the effect frequency and amount of watering on the total shoot length (Total shoots =leading shoot + lateral shoots) of LMMV.

ANOVA Table for Total Shoots

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Ppt	2	846.178	423.089	45.704	<.0001	91.408	1.000
Freq	2	176.400	88.200	9.528	.0001	19.056	.987
Ppt * Freq	4	265.422	66.356	7.168	<.0001	28.672	.997
Residual	126	1166.400	9.257				

Total shoots = leading shoot + lateral shoots

Means Table for Total Shoots

Effect: Ppt * Freq

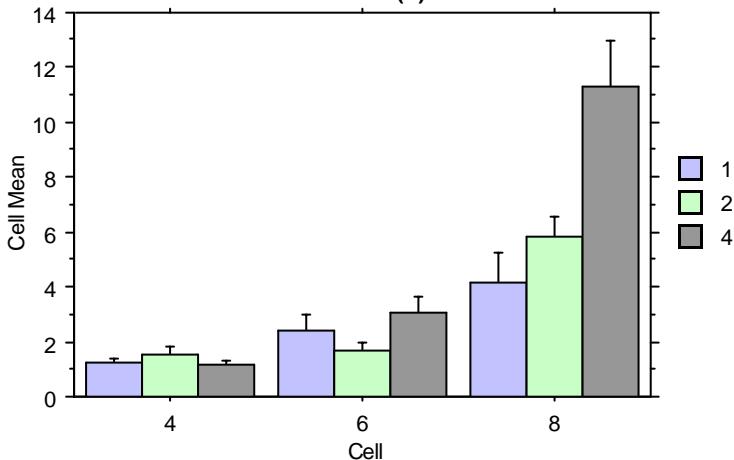
	Count	Mean	Std. Dev.	Std. Err.
4, 1	15	1.267	.458	.118
4, 2	15	1.533	1.060	.274
4, 4	15	1.200	.561	.145
6, 1	15	2.400	2.261	.584
6, 2	15	1.667	1.234	.319
6, 4	15	3.067	2.282	.589
8, 1	15	4.133	4.373	1.129
8, 2	15	5.800	3.052	.788
8, 4	15	11.333	6.433	1.661

Total ppt amount (4,6,8), Frequency/mo (1,2,4)

Interaction Bar Plot for Total Shoots

Effect: Ppt * Freq

Error Bars: ± 1 Standard Error(s)



Interaction between amt and freq is significant. Freq has no interaction at 4" and 6", but has a significant effect at 8" precipitation (**hereafter, ppt**).

Fisher's PLSD for Total Shoots**Effect: Ppt****Significance Level: 5 %**

	Mean Diff.	Crit. Diff.	P-Value	
4, 6	-1.044	1.269	.1060	S
4, 8	-5.756	1.269	<.0001	S
6, 8	-4.711	1.269	<.0001	S

Fisher's PLSD for Total Shoots**Effect: Freq****Significance Level: 5 %**

	Mean Diff.	Crit. Diff.	P-Value	
1, 2	-.400	1.269	.5340	S
1, 4	-2.600	1.269	<.0001	S
2, 4	-2.200	1.269	.0008	S

No significant difference in the total shoots length between 4" and 6" ppt.

Significant difference in the total shoots between 4" and 8" and between 6" and 8" ppt.

No significant difference in the number of shoots length between watering 1× and 2×/month.

Siginificant difference in the number of shoots between watering 1× and 4×/month and between 2× and 4×/month.

Appendix 1c. Two-factor ANOVA analysis for the effect frequency and amount of watering on the seedling survival of LMMV.

ANOVA Table for Survival July

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
ppt	2	18.296	9.148	7.968	.0033	15.935	.926
freq	2	10.296	5.148	4.484	.0263	8.968	.692
ppt * freq	4	20.370	5.093	4.435	.0114	17.742	.861
Residual	18	20.667	1.148				

Both factors (ppt and freq) have a significant affect on the number of seedlings that survived to July. The more water the greater the survival; the greater the freq, the greater the survival.

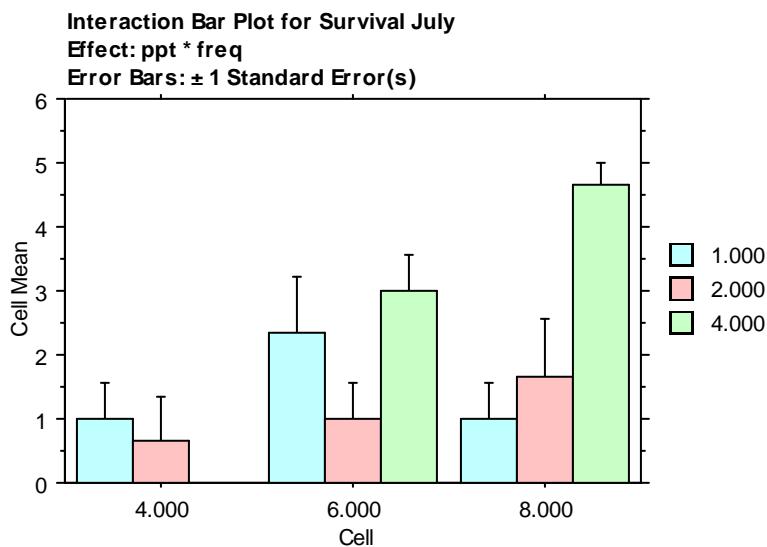
Interaction of ppt and freq also significant. More frequent watering increasing the affect of total ppt, at least at 8" ppt, see below.

Means Table for Survival July

Effect: ppt * freq

	Count	Mean	Std. Dev.	Std. Err.
4.000, 1.000	3	1.000	1.000	.577
4.000, 2.000	3	.667	1.155	.667
4.000, 4.000	3	0.000	0.000	0.000
6.000, 1.000	3	2.333	1.528	.882
6.000, 2.000	3	1.000	1.000	.577
6.000, 4.000	3	3.000	1.000	.577
8.000, 1.000	3	1.000	1.000	.577
8.000, 2.000	3	1.667	1.528	.882
8.000, 4.000	3	4.667	.577	.333

Ppt totals (4", 6", 8"), Frequency/mo (1x, 2x, 4x)



Interaction: frequency of watering affects response to ppt total, but it appears that it is significant because of its affect on the 8" watering level, and not at the 4" and 6" watering level.

Fisher's PLSD for Survival July
Effect: ppt
Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value	
4.000, 6.000	-1.556	1.061	.0065	S
4.000, 8.000	-1.889	1.061	.0015	S
6.000, 8.000	-.333	1.061	.5177	

No significant difference in number of seedlings that survived between 6" and 8" total ppt.

Fisher's PLSD for Survival July
Effect: freq
Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value	
1.000, 2.000	.333	1.061	.5177	
1.000, 4.000	-1.111	1.061	.0411	S
2.000, 4.000	-1.444	1.061	.0104	S

Water freq resulted in significant differences between 1x and 4x/mo, and 2x and 4x/mo, but not between 1x and 2x/mo.

Appendix 1d. Single-factor ANOVA analysis for the effect of frequency of watering on the photosynthetic capacity (A_{max}) of LMMV.

ANOVA Table for Photo

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Frequency	2	1987.092	993.546	78.437	<.0001	156.873	1.000
Residual	61	772.678	12.667				

Means Table for Photo

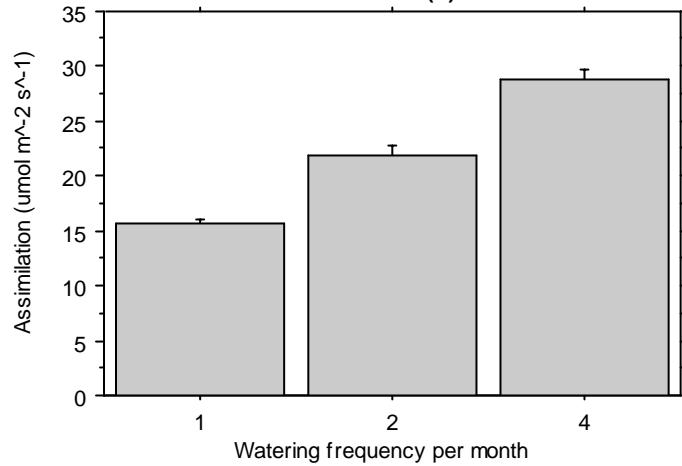
Effect: Frequency

	Count	Mean	Std. Dev.	Std. Err.
1	21	15.670	2.113	.461
2	18	21.888	3.669	.865
4	25	28.828	4.352	.870

Interaction Bar Plot for Photo

Effect: Frequency

Error Bars: ± 1 Standard Error(s)



Fisher's PLSD for Photo

Effect: Frequency

Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value	
1, 2	-6.218	2.286	<.0001	S
1, 4	-13.158	2.107	<.0001	S
2, 4	-6.940	2.200	<.0001	S

Appendix 1e. Single-factor ANOVA analysis for the effect of frequency of watering on the transpiration (E) of LMMV.

ANOVA Table for Transpiration

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Frequency	2	248.980	124.490	99.741	<.0001	199.483	1.000
Residual	61	76.136	1.248				

Means Table for Transpiration

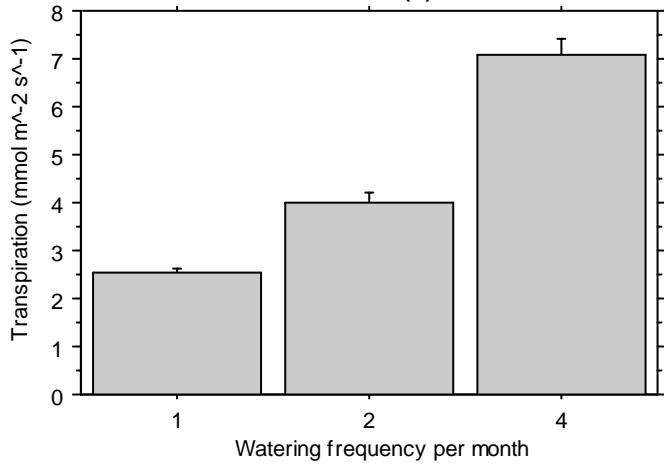
Effect: Frequency

	Count	Mean	Std. Dev.	Std. Err.
1	21	2.542	.434	.095
2	18	3.992	.855	.201
4	25	7.085	1.580	.316

Interaction Bar Plot for Transpiration

Effect: Frequency

Error Bars: ± 1 Standard Error(s)



Fisher's PLSD for Transpiration

Effect: Frequency

Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value	
1, 2	-1.450	.718	.0002	S
1, 4	-4.543	.661	<.0001	S
2, 4	-3.093	.691	<.0001	S

Appendix 1f. Single-factor ANOVA analysis for the effect of frequency of watering on the water-use efficiency, WUE (A/E) of LMMV.

ANOVA Table for WUE

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Frequency	2	46.064	23.032	51.977	<.0001	103.955	1.000
Residual	61	27.030	.443				

Means Table for WUE

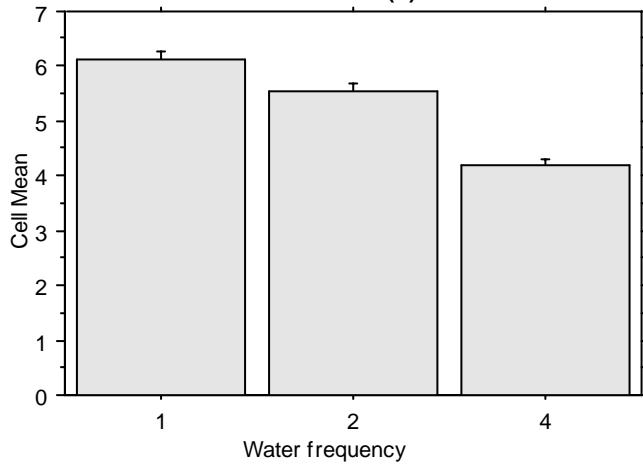
Effect: Frequency

	Count	Mean	Std. Dev.	Std. Err.
1	21	6.114	.745	.163
2	18	5.559	.536	.126
4	25	4.176	.678	.136

Interaction Bar Plot for WUE

Effect: Frequency

Error Bars: ± 1 Standard Error(s)



Fisher's PLSD for WUE

Effect: Frequency

Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value	
1, 2	.554	.428	.0119	S
1, 4	1.938	.394	<.0001	S
2, 4	1.383	.411	<.0001	S

Appendix 1g. Single-factor ANOVA analysis for the effect of amount of watering on the number of resprouted seedling of LMMV. Because only few seedlings resprouted, a 2-factor ANOVA was not possible to apply.

ANOVA Table for resprout

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
ppt	2	.854	.427	4.207	.0215	8.413	.709
Residual	43	4.364	.101				

Means Table for resprout

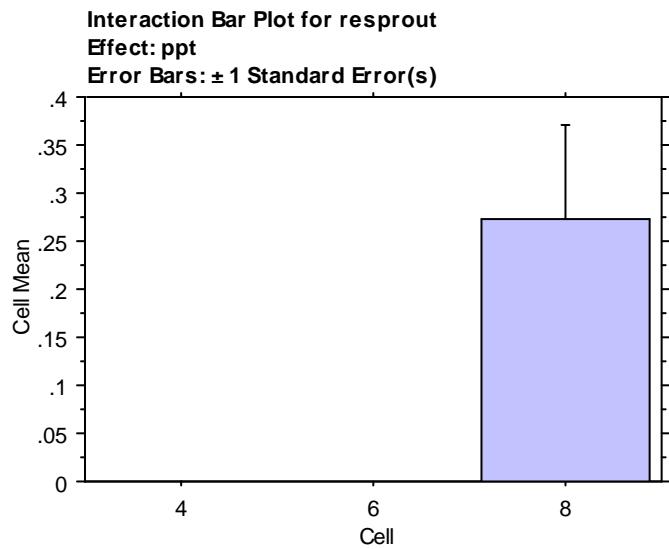
Effect: ppt

	Count	Mean	Std. Dev.	Std. Err.
4	5	0.000	0.000	0.000
6	19	0.000	0.000	0.000
8	22	.273	.456	.097

Because so many seedlings did not survive to July and the unequal sample sizes, a 2-factor ANOVA was not possible.

Ppt amount and frequency of water had to be analyzed separately. The analysis was based on only the seedlings ($n = 46$) that were alive in July.

Ppt amount significantly affected ability of plants to resprout, presumably because plants under higher ppt developed greater root mass to endure a long drought.



Fisher's PLSD for resprout
Effect: ppt
Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value
4, 6	0.000	.323	•
4, 8	-.273	.318	.0912
6, 8	-.273	.201	.0091 S

Appendix 1h. Single-factor ANOVA analysis for the effect of frequency of watering on the number of resprouted seedling of LMMV. Because so many seedlings did not survive to July and the unequal sample sizes, a 2-factor ANOVA was not possible.

ANOVA Table for resprout

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
freq	2	.381	.191	1.695	.1956	3.390	.325
Residual	43	4.836	.112				

Means Table for resprout

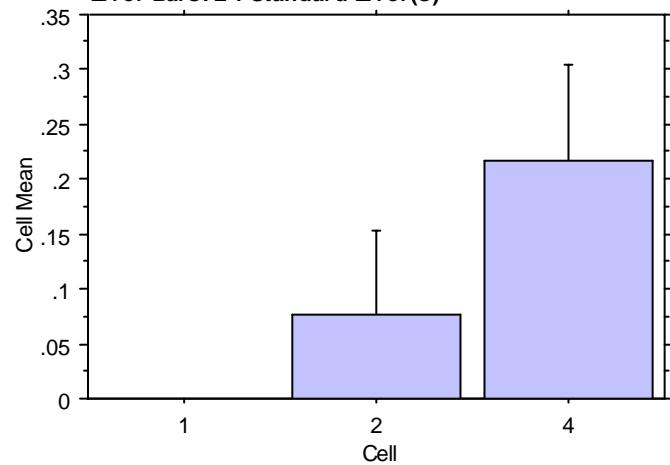
Effect: freq

	Count	Mean	Std. Dev.	Std. Err.
1	10	0.000	0.000	0.000
2	13	.077	.277	.077
4	23	.217	.422	.088

Interaction Bar Plot for resprout

Effect: freq

Error Bars: ± 1 Standard Error(s)



Fisher's PLSD for resprout

Effect: freq

Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value
1, 2	-.077	.284	.5884
1, 4	-.217	.256	.0942
2, 4	-.140	.235	.2340

Appendix 2: Tables of data used for statistical analysis.

Appendix 2a. Leading shoot length (cm) for all seedlings taken on July 7, 2006.

8" RAIN

<i>Plant ID</i>	<i>height (cm)</i>
8-4-1	59.0
8-4-2	19.5
8-4-3	43.0
8-4-4	45.0
8-4-5	35.0
8-4-6	31.0
8-4-7	46.0
8-4-8	27.0
8-4-9	24.0
8-4-10	45.0
8-4-11	31.0
8-4-12	36.0
8-4-13	18.0
8-4-14	23.0
8-4-15	25.0
8-2-1	22.0
8-2-2	29.0
8-2-3	18.0
8-2-4	18.0
8-2-5	6.0
8-2-6	33.0
8-2-7	18.0
8-2-8	31.0
8-2-9	29.0
8-2-10	30.0
8-2-11	13.0
8-2-12	15.0
8-2-13	30.0
8-2-14	11.0
8-2-15	10.0
8-1-1	7.0
8-1-2	12.0
8-1-3	10.0
8-1-4	3.0

6" RAIN

<i>Plant ID</i>	<i>height (cm)</i>
6-4-1	7.5
6-4-2	22.5
6-4-3	12.0
6-4-4	17.0
6-4-5	5.0
6-4-6	22.0
6-4-7	28.0
6-4-8	10.5
6-4-9	25.5
6-4-10	13.0
6-4-11	23.0
6-4-12	23.0
6-4-13	10.0
6-4-14	10.0
6-4-15	14.0
6-2-1	21.0
6-2-2	7.0
6-2-3	10.5
6-2-4	7.0
6-2-5	17.0
6-2-6	5.0
6-2-7	17.0
6-2-8	4.0
6-2-9	20.5
6-2-10	9.5
6-2-11	5.0
6-2-12	10.0
6-2-13	13.0
6-2-14	7.5
6-2-15	8.5
6-1-1	5.0
6-1-2	17.0
6-1-3	13.0
6-1-4	18.0

4" RAIN

<i>Plant ID</i>	<i>height (cm)</i>
4-4-1	5.0
4-4-2	10.5
4-4-3	9.0
4-4-4	5.0
4-4-5	5.0
4-4-6	12.0
4-4-7	12.0
4-4-8	15.0
4-4-9	7.0
4-4-10	3.0
4-4-11	9.0
4-4-12	3.0
4-4-13	5.0
4-4-14	4.5
4-4-15	7.0
4-2-1	7.0
4-2-2	8.0
4-2-3	8.0
4-2-4	3.0
4-2-5	6.0
4-2-6	6.0
4-2-7	17.0
4-2-8	3.5
4-2-9	4.0
4-2-10	8.5
4-2-11	4.0
4-2-12	7.0
4-2-13	12.0
4-2-14	16.5
4-2-15	6.0
4-1-1	3.0
4-1-2	15.0
4-1-3	6.0
4-1-4	7.0

8-1-5	21.0	6-1-5	20.0	4-1-5	10.0
8-1-6	34.0	6-1-6	23.0	4-1-6	11.0
8-1-7	5.0	6-1-7	13.0	4-1-7	22.0
8-1-8	7.0	6-1-8	11.0	4-1-8	5.0
8-1-9	18.0	6-1-9	4.0	4-1-9	11.0
8-1-10	7.0	6-1-10	25.0	4-1-10	3.0
8-1-11	14.0	6-1-11	9.0	4-1-11	12.0
8-1-12	29.0	6-1-12	19.5	4-1-12	7.0
8-1-13	12.0	6-1-13	10.0	4-1-13	5.0
8-1-14	20.0	6-1-14	9.0	4-1-14	dead
8-1-15	8.0	6-1-15	dead	4-1-15	dead

Appendix 2b. Total number of lateral shoots and total length (cm) observed on May 26, 2006.

4" RAIN

plant ID	# shoots	length (cm)
4-4-1	-	-
4-4-2	-	-
4-4-3	-	-
4-4-4	-	-
4-4-5	-	-
4-4-6	-	-
4-4-7	2	14
4-4-8	-	-
4-4-9	-	-
4-4-10	-	-
4-4-11	1	8
4-4-12	-	-
4-4-13	-	-
4-4-14	-	-
4-4-15	-	-
4-2-1	-	-
4-2-2	-	-
4-2-3	-	-
4-2-4	-	-
4-2-5	1	6
4-2-6	-	-
4-2-7	4	27
4-2-8	-	-
4-2-9	-	-
4-2-10	1	7
4-2-11	-	-
4-2-12	1	6
4-2-13	1	10
4-2-14	-	-
4-2-15	-	-
4-1-1	-	-
4-1-2	1	14
4-1-3	-	-
4-1-4	1	7

6" RAIN

plant ID	# shoots	length (cm)
6-4-1	-	-
6-4-2	1	4
6-4-3	4	15
6-4-4	1	2
6-4-5	-	-
6-4-6	4	24
6-4-7	8	61
6-4-8	4	25
6-4-9	2	12
6-4-10	3	15
6-4-11	-	-
6-4-12	3	31
6-4-13	1	4
6-4-14	-	-
6-4-15	-	-
6-2-1	3	21
6-2-2	-	-
6-2-3	-	-
6-2-4	-	-
6-2-5	4	15
6-2-6	-	-
6-2-7	1	2
6-2-8	1	5
6-2-9	-	-
6-2-10	1	3
6-2-11	-	-
6-2-12	-	-
6-2-13	-	-
6-2-14	-	-
6-2-15	-	-
6-1-1	-	-
6-1-2	2	9
6-1-3	3	22
6-1-4	4	33

8" RAIN

plant ID	# shoots	length (cm)
8-4-1	14	75
8-4-2	1	3
8-4-3	6	77
8-4-4	13	195
8-4-5	13	126
8-4-6	15	89
8-4-7	22	220
8-4-8	20	145
8-4-9	10	75
8-4-10	13	203
8-4-11	1	7
8-4-12	1	5
8-4-13	10	74
8-4-14	9	46
8-4-15	7	27
8-2-1	8	79
8-2-2	5	49
8-2-3	7	61
8-2-4	4	37
8-2-5	-	-
8-2-6	7	57
8-2-7	2	11
8-2-8	6	59
8-2-9	11	84
8-2-10	7	91
8-2-11	3	15
8-2-12	4	6
8-2-13	6	52
8-2-14	1	10
8-2-15	1	2
8-1-1	-	-
8-1-2	-	-
8-1-3	-	-
8-1-4	-	-

4-1-5	-	-	6-1-5	2	3	8-1-5	6	27
4-1-6	-	-	6-1-6	8	86	8-1-6	14	84
4-1-7	1	2	6-1-7	2	13	8-1-7	-	-
4-1-8	1	5	6-1-8	-	-	8-1-8	-	-
4-1-9	-	-	6-1-9	-	-	8-1-9	7	86
4-1-10	-	-	6-1-10	-	-	8-1-10	1	4
4-1-11	-	-	6-1-11	-	-	8-1-11	-	-
4-1-12	-	-	6-1-12	-	-	8-1-12	9	70
4-1-13	-	-	6-1-13	-	-	8-1-13	6	53
4-1-14	-	-	6-1-14	-	-	8-1-14	4	38
4-1-15	-	-	6-1-15	-	-	8-1-15	-	-

Appendix 2c. Resprouted LMMV plants for each set of replicates (**bold** indicates specific plant resprouted) observed on July 7, 2006.

8" RAIN		6" RAIN		4" RAIN	
Plant ID	# resprouted	Plant ID	# resprouted	Plant ID	# resprouted
8-4-1		6-4-1		4-4-1	
8-4-2		6-4-2		4-4-2	
8-4-3	2	6-4-3	0	4-4-3	0
8-4-4		6-4-4		4-4-4	
8-4-5		6-4-5		4-4-5	
8-4-6		6-4-6		4-4-6	
8-4-7		6-4-7		4-4-7	
8-4-8	3	6-4-8	0	4-4-8	0
8-4-9		6-4-9		4-4-9	
8-4-10		6-4-10		4-4-10	
8-4-11		6-4-11		4-4-11	
8-4-12		6-4-12		4-4-12	
8-4-13	0	6-4-13	0	4-4-13	0
8-4-14		6-4-14		4-4-14	
8-4-15		6-4-15		4-4-15	
8-2-1		6-2-1		4-2-1	
8-2-2		6-2-2		4-2-2	
8-2-3	0	6-2-3	0	4-2-3	0
8-2-4		6-2-4		4-2-4	
8-2-5		6-2-5		4-2-5	
8-2-6		6-2-6		4-2-6	
8-2-7		6-2-7		4-2-7	
8-2-8	1	6-2-8	0	4-2-8	0
8-2-9		6-2-9		4-2-9	
8-2-10		6-2-10		4-2-10	
8-2-11		6-2-11		4-2-11	
8-2-12		6-2-12		4-2-12	
8-2-13	0	6-2-13	0	4-2-13	0
8-2-14		6-2-14		4-2-14	
8-2-15		6-2-15		4-2-15	
8-1-1		6-1-1		4-1-1	
8-1-2		6-1-2		4-1-2	

8-1-3	0	6-1-3	0	4-1-3	0
8-1-4		6-1-4		4-1-4	
8-1-5		6-1-5		4-1-5	
8-1-6		6-1-6		4-1-6	
8-1-7		6-1-7		4-1-7	
8-1-8	0	6-1-8	0	4-1-8	0
8-1-9		6-1-9		4-1-9	
8-1-10		6-1-10		4-1-10	
8-1-11		6-1-11		4-1-11	
8-1-12		6-1-12		4-1-12	
8-1-13	0	6-1-13	0	4-1-13	0
8-1-14		6-1-14		4-1-14	
8-1-15		6-1-15		4-1-15	

Appendix 2d. Absolute mortality for each set of five replicates for each of the nine different watering treatments observed on July 7, 2006.

8" RAIN

	Set 1	Set 2	Set 3	Total
4x	0	0	1	1
2x	5	2	3	10
1x	5	4	3	12

6" RAIN

	Set 1	Set 2	Set 3	Total
4x	2	1	3	6
2x	3	4	5	12
1x	1	3	4	8

4" RAIN

	Set 1	Set 2	Set 3	Total
4x	5	5	5	15
2x	5	3	5	13
1x	5	4	3	12

Appendix 3: Phenological data

Appendix 3a. 4" Precipitation treatment: Leading shoot length (cm) for seedlings of each treatment for the period April - July 2007 (bold indicates dead plant).

Plant ID	04/07/06	04/13/06	04/21/06	05/01/06	05/05/06	05/11/06	05/17/06
4-4-1	3.0	3.0	4.5	5.0	5.0	5.0	5.0
4-4-2	6.5	10.5	10.5	10.5	10.5	10.5	10.5
4-4-3	9.0	8.0	8.5	8.0	8.0	8.0	9.0
4-4-4	6.0	5.0	5.0	5.0	5.0	5.0	5.0
4-4-5	6.0	5.0	5.0	5.0	5.0	5.0	5.0
4-4-6	12.0	12.0	12.0	12.0	12.0	12.0	12.0
4-4-7	11.0	11.5	12.0	11.0	12.0	12.5	12.0
4-4-8	12.5	15.0	15.0	15.0	15.0	15.0	15.0
4-4-9	7.5	7.0	7.0	7.0	7.0	7.0	7.0
4-4-10	3.0	3.0	3.0	3.0	3.0	3.0	3.0
4-4-11	8.5	9.0	9.0	9.0	9.0	9.0	9.0
4-4-12	4.5	3.0	3.0	3.0	3.0	3.0	3.0
4-4-13	5.0	5.0	5.0	5.0	5.0	5.0	5.0
4-4-14	4.0	4.0	4.5	4.5	4.5	4.5	4.5
4-4-15	7.5	8.0	7.0	6.0	6.0	6.0	7.0
4-2-1	7.0	7.0	8.0	7.0	7.0	7.0	7.0
4-2-2	6.0	8.0	8.0	8.0	8.0	8.0	8.0
4-2-3	7.0	7.0	8.0	8.0	8.0	8.0	8.0
4-2-4	3.0	3.0	3.0	3.0	3.0	3.0	3.0
4-2-5	3.0	4.0	6.0	6.0	6.0	5.5	6.0
4-2-6	5.5	6.0	6.0	6.0	6.0	6.0	6.0
4-2-7	6.0	7.0	9.5	11.0	12.0	12.0	14.0
4-2-8	4.0	3.5	3.5	3.5	3.5	3.5	3.5
4-2-9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4-2-10	3.0	5.0	6.0	7.0	7.0	7.0	8.0
4-2-11	2.5	4.0	4.0	4.0	4.0	4.0	4.0
4-2-12	6.0	7.0	7.0	7.0	6.0	6.0	7.0
4-2-13	4.5	6.5	11.0	11.0	11.0	11.0	11.0
4-2-14	13.0	16.5	16.5	16.5	16.5	16.5	16.5
4-2-15	5.0	6.0	7.0	7.0	6.0	6.0	6.0
4-1-1	4.0	4.5	4.0	3.0	3.0	3.0	3.0
4-1-2	6.0	6.0	8.5	12.0	13.0	14.0	14.0
4-1-3	6.0	6.5	6.0	7.0	7.0	6.0	6.0
4-1-4	5.5	5.0	6.5	8.0	7.0	8.0	8.0
4-1-5	7.5	10.0	13.5	16.0	10.0	10.0	10.0
4-1-6	7.5	9.0	11.5	11.0	11.0	11.0	11.0
4-1-7	7.5	9.5	12.5	15.0	15.0	18.0	22.0
4-1-8	4.0	5.0	5.0	5.0	5.0	5.0	6.0
4-1-9	12.0	11.0	11.0	11.0	11.0	11.5	11.0
4-1-10	5.0	5.5	5.5	5.0	3.0	3.0	3.0
4-1-11	5.5	6.0	6.0	12.0	11.0	12.0	12.0
4-1-12	4.0	4.0	4.0	5.0	5.0	5.0	5.0
4-1-13	6.5	5.0	5.0	5.0	5.0	5.0	5.0

4-1-14	N/A						
4-1-15	N/A						

Plant ID	05/25/06	06/01/06	06/08/06	06/16/06	06/22/06	06/30/06	07/07/06
4-4-1	5.0	5.0	5.0	5.0	5.0	5.0	5.0
4-4-2	10.5	10.5	10.5	10.5	10.5	10.5	10.5
4-4-3	9.0	8.0	7.0	7.0	9.0	9.0	9.0
4-4-4	5.0	5.0	5.0	5.0	5.0	5.0	5.0
4-4-5	5.0	5.0	5.0	5.0	5.0	5.0	5.0
4-4-6	12.0	12.0	12.0	12.0	12.0	12.0	12.0
4-4-7	12.0	12.0	12.0	12.0	12.0	12.0	12.0
4-4-8	15.0	15.0	15.0	15.0	15.0	15.0	15.0
4-4-9	7.0	7.0	7.0	7.0	7.0	7.0	7.0
4-4-10	3.0	3.0	3.0	3.0	3.0	3.0	3.0
4-4-11	9.0	8.0	9.0	9.0	9.0	9.0	9.0
4-4-12	3.0	3.0	3.0	3.0	3.0	3.0	3.0
4-4-13	5.0	5.0	5.0	5.0	5.0	5.0	5.0
4-4-14	4.5	4.5	4.5	4.5	4.5	4.5	4.5
4-4-15	7.0	7.0	7.0	7.0	7.0	7.0	7.0
4-2-1	7.0	7.0	7.0	7.0	7.0	7.0	7.0
4-2-2	8.0	8.0	8.0	8.0	8.0	8.0	8.0
4-2-3	8.0	8.0	8.0	8.0	8.0	8.0	8.0
4-2-4	3.0	3.0	3.0	3.0	3.0	3.0	3.0
4-2-5	6.0	6.0	6.0	6.0	6.0	6.0	6.0
4-2-6	6.0	6.0	6.0	6.0	6.0	6.0	6.0
4-2-7	15.0	15.0	15.0	16.0	16.0	17.0	17.0
4-2-8	3.5	3.5	3.5	3.5	3.5	3.5	3.5
4-2-9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4-2-10	7.5	7.0	7.0	7.0	8.0	8.0	8.5
4-2-11	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4-2-12	7.0	6.0	7.0	7.0	7.0	7.0	7.0
4-2-13	11.0	11.0	11.0	11.0	12.0	12.0	12.0
4-2-14	16.5	16.5	16.5	16.5	16.5	16.5	16.5
4-2-15	6.0	6.0	6.0	6.0	6.0	6.0	6.0
4-1-1	3.0	3.0	3.0	3.0	3.0	3.0	3.0
4-1-2	14.0	15.0	14.0	14.0	15.0	15.0	15.0
4-1-3	6.0	6.0	6.0	6.0	6.0	6.0	6.0
4-1-4	7.0	7.0	7.0	7.0	7.0	7.0	7.0
4-1-5	10.0	10.0	10.0	10.0	10.0	10.0	10.0
4-1-6	11.0	11.0	11.0	11.0	11.0	11.0	11.0
4-1-7	22.0	22.0	22.0	22.0	22.0	22.0	22.0
4-1-8	5.0	5.0	5.0	5.0	5.0	5.0	5.0
4-1-9	11.0	11.0	11.0	11.0	11.0	11.0	11.0
4-1-10	3.0	3.0	3.0	3.0	3.0	3.0	3.0
4-1-11	12.0	12.0	12.0	12.0	12.0	12.0	12.0
4-1-12	7.0	7.0	7.0	7.0	7.0	7.0	7.0
4-1-13	5.0	5.0	5.0	5.0	5.0	5.0	5.0
4-1-14	N/A						
4-1-15	N/A						

Appendix 3b. 6" Precipitation treatment: Leading shoot length (cm) for seedlings of each treatment for the period April - July 2007 (bold indicates dead plant).

Plant ID	04/07/06	04/13/06	04/21/06	05/01/06	05/05/06	05/11/06	05/17/06
6-4-1	8.0	8.0	7.5	7.5	7.5	7.5	7.5
6-4-2	6.5	10.5	14.0	17.0	17.0	21.0	22.5
6-4-3	4.0	5.0	6.5	8.0	8.0	8.0	9.0
6-4-4	3.0	9.5	13.0	13.0	14.0	15.0	17.0
6-4-5	4.5	6.0	5.0	5.0	5.0	5.0	5.0
6-4-6	4.0	5.5	8.5	13.0	14.0	16.5	18.5
6-4-7	17.5	18.0	19.0	22.0	22.0	23.0	28.0
6-4-8	8.0	9.5	10.0	10.0	9.0	9.5	11.0
6-4-9	20.0	21.5	23.0	24.0	25.0	25.5	25.5
6-4-10	13.0	13.0	13.0	14.0	14.0	13.0	13.0
6-4-11	6.5	7.0	10.0	12.0	13.0	16.0	21.0
6-4-12	19.0	22.0	20.0	22.0	23.0	23.0	23.0
6-4-13	5.5	7.5	8.5	10.0	10.0	11.0	10.0
6-4-14	9.0	10.5	13.0	11.0	10.0	10.0	10.0
6-4-15	14.0	14.5	16.0	14.0	14.0	14.0	14.0
6-2-1	12.0	12.5	18.0	20.0	20.0	20.0	20.5
6-2-2	7.0	7.0	7.0	7.0	7.0	7.0	7.0
6-2-3	6.5	7.0	9.0	11.0	11.0	11.5	11.5
6-2-4	3.0	3.5	3.5	8.0	7.0	8.0	7.0
6-2-5	5.5	7.0	9.5	11.0	12.0	15.0	17.0
6-2-6	6.0	6.5	5.0	5.0	5.0	5.0	5.0
6-2-7	4.0	6.0	8.5	10.0	11.0	14.0	17.0
6-2-8	5.5	6.0	5.5	5.0	5.0	4.0	4.0
6-2-9	18.0	19.5	19.5	20.0	20.0	20.0	20.5
6-2-10	9.0	10.0	8.5	9.0	8.0	9.0	9.5
6-2-11	4.0	5.0	5.5	6.0	5.0	5.0	5.0
6-2-12	7.0	8.0	8.0	9.0	9.0	10.0	10.0
6-2-13	12.0	12.5	13.0	14.0	13.0	13.0	13.0
6-2-14	7.0	7.5	7.5	7.5	7.5	7.5	7.5
6-2-15	5.0	4.5	8.5	8.5	8.5	8.5	8.5
6-1-1	4.0	5.0	4.5	5.0	5.0	5.0	5.0
6-1-2	6.5	10.0	12.5	14.0	16.0	17.0	17.0
6-1-3	7.5	8.0	7.0	9.0	10.0	9.5	11.0
6-1-4	11.0	12.0	14.0	15.0	15.0	15.0	15.5
6-1-5	5.0	6.0	10.0	13.0	14.0	19.0	20.0
6-1-6	9.5	12.0	14.0	19.0	19.0	22.0	24.0
6-1-7	4.5	6.0	7.0	9.0	11.0	13.0	16.5
6-1-8	8.0	9.0	10.0	11.0	11.0	11.0	11.0
6-1-9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
6-1-10	12.0	13.5	16.0	17.0	17.0	21.0	25.0
6-1-11	9.0	10.5	9.0	9.0	9.0	9.0	9.0
6-1-12	8.0	11.0	13.0	15.0	16.0	18.0	19.5
6-1-13	11.0	11.0	10.5	10.0	10.0	10.0	10.0
6-1-14	7.5	8.5	9.0	9.0	9.0	9.0	9.0
6-1-15	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Plant ID	05/25/06	06/01/06	06/08/06	06/16/06	06/22/06	06/30/06	07/07/06
6-4-1	7.5	7.5	7.5	7.5	7.5	7.5	7.5
6-4-2	22.5	22.5	22.5	22.5	22.5	22.5	22.5
6-4-3	12.0	12.0	12.0	12.0	12.0	12.0	12.0
6-4-4	17.0	17.0	17.0	17.0	17.0	17.0	17.0
6-4-5	5.0	5.0	5.0	5.0	5.0	5.0	5.0
6-4-6	22.0	22.0	22.0	22.0	22.0	22.0	22.0
6-4-7	28.0	28.0	28.0	28.0	28.0	28.0	28.0
6-4-8	12.0	11.0	11.0	11.0	11.0	11.0	10.5
6-4-9	25.5	25.5	25.5	25.5	25.5	25.5	25.5
6-4-10	13.0	13.0	13.0	13.0	13.0	13.0	13.0
6-4-11	23.0	23.0	23.0	23.0	23.0	23.0	23.0
6-4-12	24.0	23.0	23.0	23.0	23.0	23.0	23.0
6-4-13	10.0	10.0	10.0	10.0	10.0	10.0	10.0
6-4-14	10.0	10.0	10.0	10.0	10.0	10.0	10.0
6-4-15	14.0	14.0	14.0	14.0	14.0	14.0	14.0
6-2-1	21.0	14.0	17.0	20.0	20.0	21.0	21.0
6-2-2	7.0	7.0	7.0	7.0	7.0	7.0	7.0
6-2-3	10.5	10.5	10.5	10.5	10.5	10.5	10.5
6-2-4	7.0	7.0	7.0	7.0	7.0	7.0	7.0
6-2-5	17.0	17.0	17.0	17.0	17.0	17.0	17.0
6-2-6	5.0	5.0	5.0	5.0	5.0	5.0	5.0
6-2-7	17.0	17.0	17.0	17.0	17.0	17.0	17.0
6-2-8	4.0	4.0	4.0	4.0	4.0	4.0	4.0
6-2-9	20.5	20.5	20.5	20.5	20.5	20.5	20.5
6-2-10	9.5	9.5	9.5	9.5	9.5	9.5	9.5
6-2-11	5.0	5.0	5.0	5.0	5.0	5.0	5.0
6-2-12	10.0	10.0	10.0	10.0	10.0	10.0	10.0
6-2-13	13.0	13.0	13.0	13.0	13.0	13.0	13.0
6-2-14	7.5	7.5	7.5	7.5	7.5	7.5	7.5
6-2-15	8.5	8.5	8.5	8.5	8.5	8.5	8.5
6-1-1	5.0	5.0	5.0	5.0	5.0	5.0	5.0
6-1-2	17.0	17.0	17.0	17.0	17.0	17.0	17.0
6-1-3	11.0	10.0	10.0	11.0	12.0	13.0	13.0
6-1-4	17.0	17.0	17.0	18.0	18.0	19.0	18.0
6-1-5	20.0	20.0	20.0	20.0	20.0	20.0	20.0
6-1-6	22.0	24.0	23.0	23.0	23.0	23.0	23.0
6-1-7	13.0	13.0	13.0	13.0	13.0	13.0	13.0
6-1-8	11.0	11.0	11.0	11.0	11.0	11.0	11.0
6-1-9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
6-1-10	25.0	25.0	25.0	25.0	25.0	25.0	25.0
6-1-11	9.0	9.0	9.0	9.0	9.0	9.0	9.0
6-1-12	19.5	19.5	19.5	19.5	19.5	19.5	19.5
6-1-13	10.0	10.0	10.0	10.0	10.0	10.0	10.0
6-1-14	9.0	9.0	9.0	9.0	9.0	9.0	9.0
6-1-15	N/A						

Appendix 3c. 8" Precipitation treatment: Leading shoot length (cm) for seedlings of each treatment for the period April - July 2007 (bold indicates dead plant).

Plant ID	04/07/06	04/13/06	04/21/06	05/01/06	05/05/06	05/11/06	05/17/06
8-4-1	16.0	18.5	19.0	20.0	21.0	21.0	20.5
8-4-2	12.0	13.0	15.0	15.0	16.0	19.0	19.5
8-4-3	19.0	20.0	20.0	21.0	21.0	22.0	25.0
8-4-4	8.0	12.0	16.0	17.0	17.0	19.0	26.0
8-4-5	16.0	17.5	18.0	15.0	15.0	15.0	16.0
8-4-6	6.0	7.0	17.0	17.0	19.0	19.5	26.0
8-4-7	24.0	26.0	25.0	28.0	28.0	28.0	30.5
8-4-8	11.0	13.5	17.0	17.0	17.0	18.0	20.0
8-4-9	13.0	16.0	16.0	17.0	17.0	17.5	17.0
8-4-10	5.0	13.5	15.0	15.0	16.0	16.0	22.0
8-4-11	6.0	9.0	11.5	16.0	16.0	20.0	25.0
8-4-12	4.0	7.0	18.0	22.0	24.0	28.0	32.5
8-4-13	5.0	8.5	12.5	10.0	10.0	11.5	16.0
8-4-14	9.0	14.0	16.0	19.0	21.0	24.0	28.0
8-4-15	7.0	9.0	12.0	14.0	15.0	20.0	25.0
8-2-1	10.0	13.0	15.0	18.0	18.0	19.0	21.5
8-2-2	9.5	11.0	16.0	21.0	24.0	23.0	27.0
8-2-3	6.0	7.0	6.0	7.0	8.0	9.0	10.5
8-2-4	5.0	7.5	8.5	12.0	14.0	12.0	17.0
8-2-5	8.0	9.0	8.5	7.0	8.0	7.0	6.0
8-2-6	17.0	20.0	24.0	28.0	29.0	29.5	33.0
8-2-7	9.0	11.0	12.0	13.0	13.0	14.0	16.5
8-2-8	15.0	16.5	19.0	22.0	25.0	27.0	29.5
8-2-9	13.0	15.0	18.0	19.0	20.0	21.0	27.0
8-2-10	4.0	6.0	10.0	16.0	17.0	19.5	27.0
8-2-11	11.0	12.0	11.5	12.0	11.0	11.0	12.0
8-2-12	9.0	10.5	12.0	13.0	14.0	15.0	15.0
8-2-13	11.5	13.5	14.0	16.0	17.0	18.0	23.0
8-2-14	7.0	8.0	11.0	11.0	12.0	11.0	11.0
8-2-15	10.0	11.0	10.0	10.0	10.0	10.0	10.0
8-1-1	11.0	11.5	7.0	7.0	7.0	7.0	7.0
8-1-2	9.5	11.5	12.5	12.0	12.0	12.0	12.0
8-1-3	12.0	12.0	12.0	10.0	10.0	10.0	10.0
8-1-4	4.0	4.0	3.0	3.0	3.0	3.0	3.0
8-1-5	10.0	12.0	14.0	16.0	18.0	23.0	25.0
8-1-6	18.0	24.0	24.0	25.0	26.0	29.0	30.5
8-1-7	7.0	7.0	6.5	5.0	5.0	5.0	5.0
8-1-8	3.0	4.0	4.0	7.0	7.0	7.0	7.0
8-1-9	10.0	12.5	14.0	13.0	17.0	17.0	17.0
8-1-10	6.0	5.5	8.0	7.0	8.0	7.5	7.5
8-1-11	15.5	15.0	14.0	13.0	14.0	14.0	14.0
8-1-12	9.0	11.0	14.0	17.0	18.0	23.0	26.0
8-1-13	7.0	11.0	13.0	17.0	17.0	18.5	18.5
8-1-14	9.0	9.0	11.0	11.0	13.0	15.5	18.0
8-1-15	9.0	10.0	7.5	8.0	8.0	8.0	8.0

